

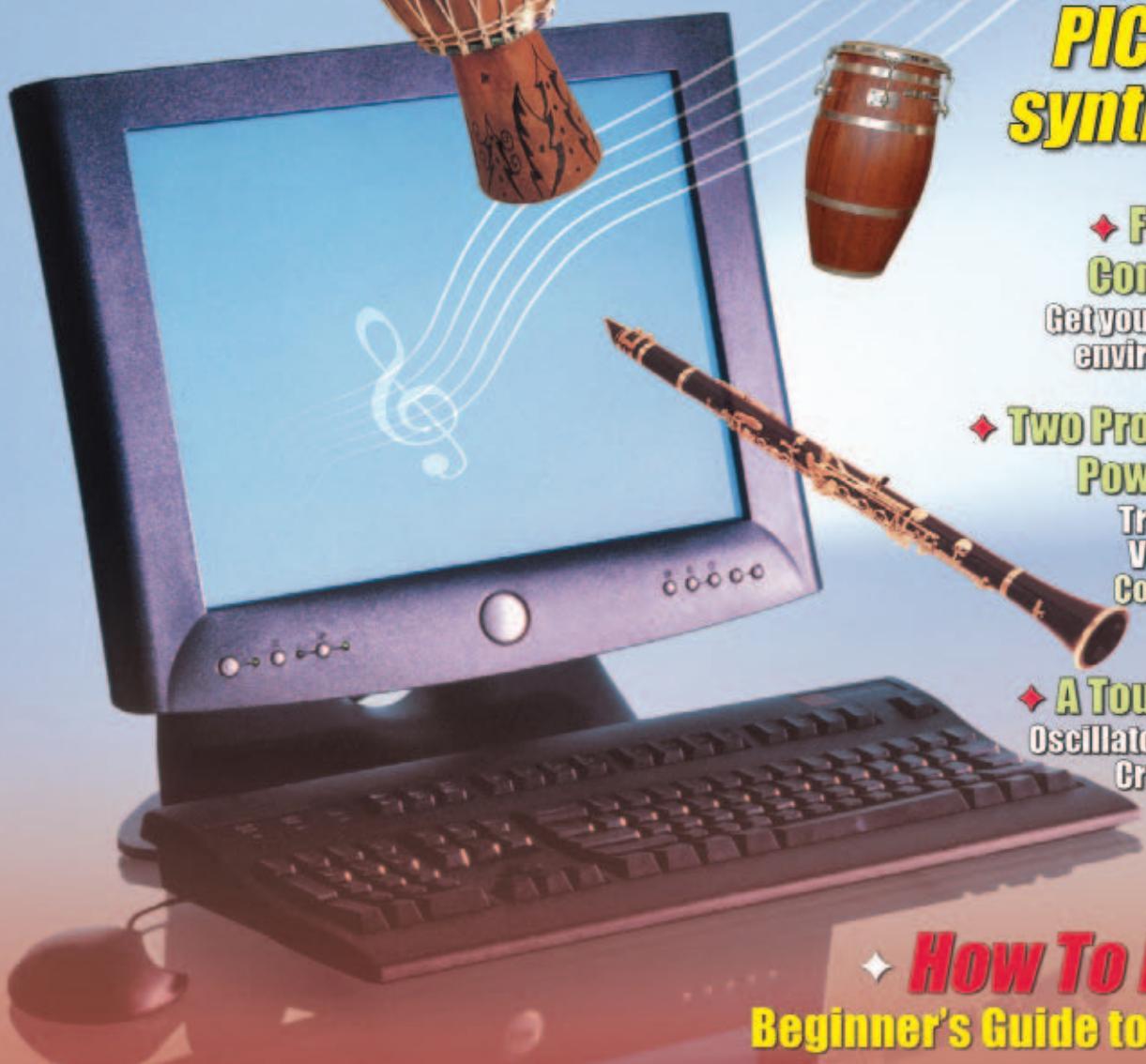
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Contents

Features

49 FPGAs at the Command Line

■ By Bob Smith

The problem with using Field Programmable Gate Arrays is that you have to learn a design language and then set up a fairly complex development environment to write programs in. That problem is addressed here.

54 Power MOSFETs ■ By Gerard Fonte

Experience for yourself how power MOSFETs are an inexpensive and easy way to control significant power by building the two projects presented this month using what you learned last month.



Page 36



Page 41

Projects

36 Garage Access Goes Digital

Keypad access is a great convenience and with this unit you can trigger activation of up to two garage doors! ■ By Jay Carter

●●●● Advanced Level

41 High Resolution Time-Lapse Movies Using a Still Camera

CamTim is a digital hack to convert your camera into a high-res time-lapse camcorder.

■ By Balakumar Balasubramanian

●●●● Advanced Level

44 Makin' MIDI with mistralXG

mistralXG is a USB connected, PIC-based synthesizer that will help you turn your computer into a music machine. ■ By Steve Russell

●●●● Advanced Level

Departments

08	DEVELOPING PERSPECTIVES	67	ELECTRO-NET NV WEBSTORE
10	READER FEEDBACK	86	CLASSIFIEDS
32	NEW PRODUCTS	90	TECH FORUM
34	SHOWCASE	92	AD INDEX

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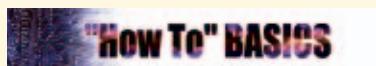
60 A Touch of Spice ■ By Peter Stonard

In this final part, take a look at oscillator circuits that create their own signal during simulation.

64 How To: A Guide to Soldering

■ By James L. Antonakos

Never soldered before? Now you can learn how!



Columns

12 TechKnowledgey 2009

Events, Advances, and News

Topics covered include DNA analysis, owning a Cray, Nabaztags explained, plus more.

16 PICAXE Primer

Sharpening Your Tools of Creativity

Implementing a serial data link with the IR multi-board.

24 Open Communication

The Latest in Networking and Wireless Technologies

Converting to digital TV.

27 Q & A

Reader Questions Answered Here

CO₂ laser power supply, a cycling circuit, LED replacement of incandescent bulbs, more.

68 The Design Cycle

Advanced Techniques for Design Engineers

A reasonable replacement for RS-232.

74 Smiley's Workshop

An AVR C Programming Series

The wearable alarm clock.

78 Near Space

Approaching the Final Frontier

The Great Plains Super Launch 2008.

81 Personal Robotics

Understanding, Designing & Constructing Robots

Pneumatics in robotics.

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by Bryan Bergeron, Editor

DEVELOPING PERSPECTIVES

Energy Harvesting

The combination of unstable oil prices, pressure to identify green alternatives to fossil fuel,

and a poor economy has renewed interest in economical alternatives to petroleum-based energy sources. While coal, wind, and solar hold promise, one of the most

technologically intriguing approaches to powering electronic devices is energy harvesting, which involves siphoning off relatively small amounts of energy from an ongoing process.

The poster child for mechanical energy harvesting is the perpetual, self-wound wristwatch. Walking and other normal body movement is typically sufficient to keep a self-wound watch going.

Furthermore, unless the wearer has a sedentary job and lifestyle, there is no need to consciously shake the watch. Reclaiming ambient energy is almost like getting energy for nothing. In this regard, energy harvesting is different from manually operating self-charging devices such as flashlights that must be shaken vigorously for a minute or more, emergency radios with built-in generators that must be cranked.

There have been numerous demonstrations of energy harvesting using piezoelectrics, ranging from sidewalks and backpacks to combat boots. Piezoelectrics harvest energy by converting an applied stress to an electrical charge. In the case of sidewalks, the stress generated by the movement of pedestrians is converted to an electric charge. Similarly, piezoelectric backpack straps and piezoelectric elements in the heels of combat boots convert the bouncing and pounding to useful energy by charging a supercap or battery.

The high cost of installation and maintenance and the relatively small return on investment have kept energy harvesting either in the lab or in highly publicized (but short-lived) demonstration projects. What's been lacking is an affordable, general-purpose energy harvesting technology that can be applied to a variety of application areas with a

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high return on investment. For example, while energy-generating sidewalks may – at best – illuminate a store sign, personal energy harvesting systems could save lives. Think backup power for a cardiac pacemaker or a telemetry system for a soldier stranded for weeks without any other means of charging the batteries in his communications gear.

I had a chance to evaluate a general-purpose energy harvesting device about the size of a 9V battery. The piezo-based device is called Joule-Thief, from AdaptivEnergy (www.rlpenergy.com). The electrical equivalent of a self-wound watch, the Joule-Thief converts movement into electrical energy. That is, the Joule-Thief transforms the movement of a piezoelectric sensor to a 3.6V output. The movement could be from walking, running, the vibration of an engine, or the rocking motion of a boat moored to a dock. Regardless of the input source, the output is on the order of 1 mW /second – enough to power the transmitter that accompanies the demonstration kit.

While AdaptivEnergy plans to offer their energy harvester at about \$10 per unit, the full evaluation kit is currently priced at about \$500 in single unit quantities. If you don't want to wait until this summer to experiment with a more affordable Joule-Thief, then consider experimenting with an ordinary piezoelectric transducer, diode, and supercap. My favorite source for transducers is Parallax, which sells a Piezo Film sensor manufactured by Measurement Specialties (www.msisa.com) for about \$2.

You can find Piezo sensors at Digi-Key and Mouser, as well. You probably won't be able to harvest enough energy to power a transmitter with a single sensor, but you should be able to track energy capture with a voltmeter or micro-ammeter.

If you want to learn more about how the Joule-Thief operates, see the AdaptivEnergy website where you'll find several informative PDFs available for free download. Similarly, information is available on the piezo Film Vibra Tab vibration sensor at the Parallax website (www.parallax.com).

I don't want to give the impression that piezo is synonymous with energy harvesting. For example, there is promise in using the temperature differential between the body and the environment as a source of energy.

If you have a working energy harvesting circuit or device – regardless of the technology – please let me hear from you. I'd like to share your experiences with our other readers. **NV**

RF Specialists

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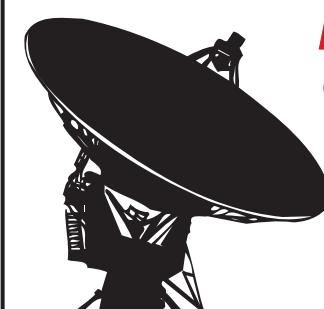


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READER FEEDBACK

FEELING DEGRADATION

To get straight to the point, my question is basically this: "What is pixelation?" Here is my short story: About a year and a half ago, I switched (finally) to digital cable from analog cable. Everything was great until this condition on our Sony Trinitron (2003 Model) screen appeared. It looked like a bunch of small-box like squares on the screen. The sound also was intermittent. This condition could sometimes last five minutes or a few hours. I called our cable company and they said we had "pixelation!!" Since then, we have switched cable boxes twice. No improvement! When I took each cable box back to try a new one, I would receive free channels (movie) for a while with a small price reduction on the cable bill. But the company will not tell me exactly what pixelation is.

It seems to me that it is something that can't be corrected. My guess is that it has to do with the ionosphere and some type of signal interference because it heats up and scatters electrons to cause radio wave distortion. So, if you could please help me with this TV (cable) problem I would really be in debt to you!!

Alan J. Smith

Digital and analog communications differ in several important ways. One is signal degradation. Analog communications degrade gradually as the noise level or signal attenuation increases. Digital communications, on the other hand, can be relatively immune to low to moderate noise or to a moderate degree of attenuation – by virtue of redundancy (i.e., encoding) and error correction schemes. What you're seeing is the result of signal degradation past what can be fully recovered by digital signal processing routines. Too much data are lost to recompose the full resolution image, so the display algorithm creates a lower resolution version.

The bottom line is that the signal isn't clean enough for your video system to reconstitute a high resolution image. It could be the fault of your cable service, your equipment, or a local source of interference. Interference could come from a defective microwave oven, a police or ham radio operator, cordless phone, or any number of electronic devices. You can try installing an EMI filter at your set box top and on the feed from your cable company to minimize interference.

Editor Bryan

continued on page 91

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FOUNDER/ASSOCIATE PUBLISHER

Jack Lemieux

PUBLISHER

Larry Lemieux
publisher@nutsvolts.com

ASSOCIATE PUBLISHER/ VP OF SALES/MARKETING

Robin Lemieux
display@nutsvolts.com

EDITOR

Bryan Bergeron
techedit@nutsvolts@yahoo.com

CONTRIBUTING EDITORS

Jeff Eckert	Russ Kincaid
Vern Graner	Fred Eady
Ron Hackett	Louis Frenzel
Joe Pardue	Paul Verhage
James Antonakos	Peter Stonard
Bob Smith	Gerard Fonte
Jay Carter	Steve Russell
Balakumar Balasubramaniam	

CIRCULATION DIRECTOR

Tracy Kerley
subscribe@nutsvolts.com

SHOW COORDINATOR

Audrey Lemieux

MARKETING COORDINATOR

WEBSTORE

Brian Kirkpatrick
sales@nutsvolts.com

WEB CONTENT

Michael Kaudze
website@nutsvolts.com

PRODUCTION/GRAFICS

Shannon Lemieux
A.J. Cohen

ADMINISTRATIVE ASSISTANT

Debbie Stauffacher

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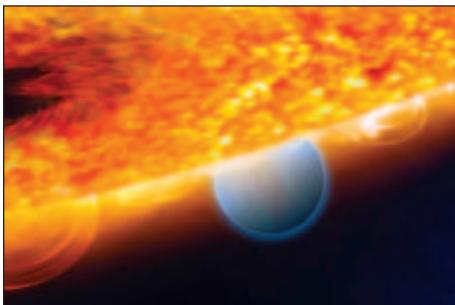




■ BY JEFF ECKERT

ADVANCED TECHNOLOGY

CO₂ LOCATED ON EXOPLANET



COURTESY OF ESA, NASA, M. KORNMESSER (ESA/HUBBLE), AND STSCL.

■ Artist's view of exoplanet orbiting the star HD 189733.

In December, researchers at NASA's Jet Propulsion Laboratory in Pasadena, CA, announced a new ray of hope for those who dream of discovering life on other worlds. Researcher Mark Swain was using the Hubble Space Telescope's near-infrared camera and multiobject spectrometer to study infrared light emitted by HD 189733b — a Jupiter-size planet located in the Vulpecula constellation — about 63 light-years away. It is so-named because it orbits the star designated HD 189733 by the International Astronomical Union. (However, feel free to call it "Aunt Zelda" if your check to the International Star Registry cleared.)

In any event, Swain discovered carbon dioxide in the atmosphere, which is the first time the gas has been detected in a planet orbiting a star other than our own. This is considered to be an important step toward finding chemical biotracers of extraterrestrial life. He also found carbon monoxide, but, "The carbon dioxide is the main reason for the excitement because, under the right circumstances, it could have a connection to biological activity as it does on Earth. The very fact we are able to detect it and estimate its

abundance is significant for the long-term effort of characterizing planets to find out what they are made of and if they could be a possible host for life."

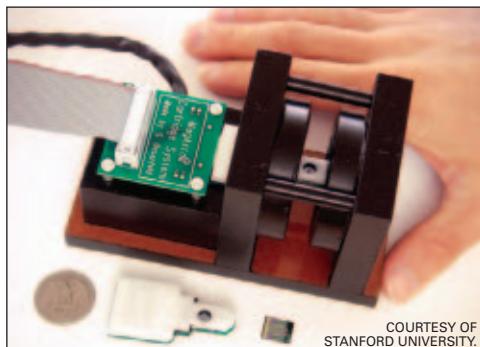
Unfortunately, HD 189733b is too hot to support life as we know it, but at least it provides proof of concept for continuing exploration.

BLOOD SCANNER DETECTS CANCER MARKERS

Back in May 2006, Prof. Shan Wang, an associate professor at Stanford University (www.stanford.edu), announced the development of the MagArray™ chip — a nanotech device that employs 64 embedded sensors to monitor for changes in nearby magnetic fields. At the time, he predicted that it could lead to improvements in medical instrumentation, particularly in the realm of cancer detection.

Because magnetism stands out more than fluorescence — which is the basis of current sensor instruments — if a cancer cell could be made to trigger a magnetic change, that could enable a more sensitive cancer detector. It now appears that Prof. Wang's efforts have paid off, as he recently unveiled a prototype MagArray-based blood scanner that can find cancer-associated proteins in a blood serum sample in less than an

■ The prototype MagArray scanner.



COURTESY OF STANFORD UNIVERSITY.

hour, and with much greater sensitivity than existing commercial devices. In fact, the device is tens to hundreds of times more sensitive, so the proteins can be found while there are relatively few of them in the bloodstream.

Wang noted, "The earlier you can detect a cancer, the better chance you have to kill it. This could be especially helpful for lung cancer, ovarian cancer, and pancreatic cancer, because those cancers are hidden in the body."

A minor drawback is that a patient's blood sample has to be processed in a centrifuge to separate out the biomarker-containing serum, so the instrument will have to be used in a hospital or lab. This pretty much eliminates the possibility of home testing. But it still should raise the standard not only for cancer detection but also for verifying heart attacks in emergency room patients who are suffering from chest pains. (As in the case of cancer, heart cell death is associated with the release of specific biomarker proteins.)

The next step is clinical testing and trials to obtain regulatory approval, which will be done by Wang's startup company, MagArray, Inc.

COMPUTERS AND NETWORKING

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■ The 1980's Cray X-MP, with its cooling system exposed, and the 2008 Cray CX1.



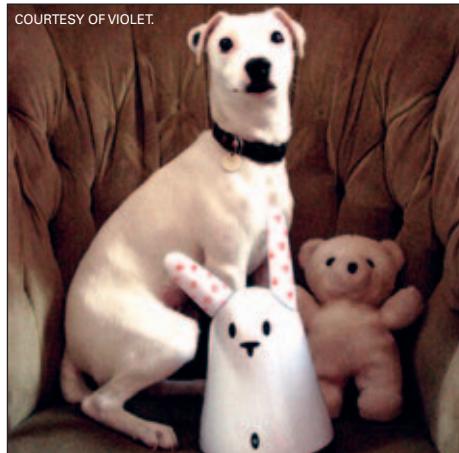
million plus the cost of disks. At that rate, the dream of running your own Cray supercomputer was pretty much unthinkable.

As of last November, it became thinkable. That's when the company introduced the Cray CX1 line of personal supercomputers, aimed at office settings in markets including financial services, oil and gas, life sciences, government, and academic institutions. The machine is based on the NVIDIA (www.nvidia.com) Tesla C1060 GPU processor, which actually owes its development to the demands of the gaming industry. Each Tesla processor has hundreds of cores that deliver nearly 1 TFLOP of peak performance, and the CX1 can be configured with up to four of them, thus providing roughly 4,000 times the performance of its great-great grandfather.

Reportedly, you can pick one up for about \$25,000, which sounds like pretty much of a bargain, all things considered. Details are available at www.cray.com. And if you don't find something you like there, keep browsing. Tesla-based personal supercomputers are available or are soon

to come from some other vendors, including AMAX, Colfax, Microway, Western Scientific, and, yes, Dell.

WHAT'S A NABAZTAG?



■ Nabaztag the rabbit with other terminally cute things.

Good question. First of all, the name is Armenian for "rabbit," which explains its appearance. Or vice versa. Secondly, it is described by its manufacturer, Violet (www.violet.net), as a "smart object," which doesn't narrow things down much. It is essentially a Wi-Fi multipurpose device that does things like provide weather, news, and stock market reports (either audibly or via flashing lights); plays music; wakes you up; alerts you to email arrivals; etc. But it also brings a potentially irritating cuteness into your life, as it apparently can sing to you, make impromptu comments, read poetry, and even do Tai Chi in its spare time.

Nabaztag blinks, moves its ears, obeys spoken commands, reads RFIDs, and speaks 16 languages. And it's programmable, so you can add services using an API or download existing services from other users. In fact, there are communities of owners with whom you can keep in touch and your Nabaztag can even marry someone else's. But enough of that.

There's always the technical side, so be advised that it employs a PIC18F6525 microcontroller, an 802.11b Wi-Fi adapter, an ML2870 audio-PCM sound generator, a TLC5922 LED controller, and two motors that drive the ears. It's

Mac/PC/Linux compatible, and it has a built-in 2W speaker, a mic, and a jack for external speakers.

The bottom line is that the little bunny will run you about \$200. According to Violet, "Soon, every Thing will be connected to the Internet. It might be a good idea to start with a Rabbit." Yeah, maybe, as long as it doesn't cut into your Second Life time too much. Details at www.nabaztag.com.

CIRCUITS AND DEVICES SEALED, FIRE-RETARDANT ROTARY SWITCH

Built by Lorlin Electronics and available through Saelig Co. is a new series of IP65-sealed components manufactured from UL/VO-compliant fire-retardant materials, making them perfect if your designs are intended for hot, outdoor, or otherwise harsh environments (or are just lousy and tend to smoke when you switch them on).

The CKS rotary switches are 27.5 mm diameter single-wafer components, available with either solder or PC board terminals. Up to four poles are available, with a maximum of 12 positions plus shorting, and an adjustable stop restricts the number

■ The CKS series switches can handle temperatures from -30 to +185°C.



COURTESY OF SAELIG

INDUSTRY AND THE PROFESSION

COMPANIES TEAM UP ON BATTERIES

Boston-Power (www.boston-power.com) is a relatively tiny player in the Lithium-Ion battery game, but it was recently announced that the company's next-generation Sonata® battery will soon be available as an optional upgrade for the Hewlett-Packard (www.hp.com) Enviro Series notebook computers.

The upgrade will cost about \$20 to \$30. According to Boston-Power, "Sonata is the longest-lasting and fastest-charging Li-Ion battery cell available." The batteries can be charged to 80 percent capacity in only half an hour, will accept 1,000 charges before capacity starts to degrade, and are warranted to last three years (and your notebook will probably be stolen before that).

Various configurations will be available for end applications

ranging from consumer electronics to transportation.

ECONOMIC CRISIS TO BUMP SOLAR INDUSTRY

According to The Information Network — a market research group — the ongoing economic downturn and credit problems will have a decidedly negative effect on solar panel manufacturers. A TIN spokesman observed, "Newly installed solar capacity will reach only 7.1 GW in 2009, equivalent to a global growth rate of 26 percent, down from our forecast of 49 percent growth earlier this year."

The good news — if you're planning on installing solar panels this year — is that panel prices are predicted to sink by 20 to 30 percent as the global inventory doubles. Recovery is in the works for 2010, however, with a projected 48 percent growth. Details are available at www.theinformationnet.com, but note that full reports will run you \$2,595 each.

of positions in use. The body has gold-flashed or gold-plated contacts, and spindles may be specified with special flats, slots, or knurls. The switches are rated at 150 mA @ 250V AC/DC, with a life expectancy of 10,000 cycles. The operating temperature range is -30 to +185°C, and its proof voltage is 1,500 VAC.

Intended applications include portable outdoor equipment, marine applications, vehicle controls, test and measurement, etc. Prices were not specified, so you'll have to contact www.saelig.com if you're interested.

QUICK DNA ANALYSIS

This product isn't for everyone, but maybe you're a private investigator

or have watched too many CSI episodes, or just aren't sure those little monsters are really your kids. In such cases, you could probably use a new instrument developed by Japan's NEC Corp. (www.nec.com) with assistance from Aida Engineering.

Billed as the world's first portable human DNA analyzer, it integrates all of the steps in the analysis process: (1) cell collection; (2) DNA extraction; (3) polymerase chain reaction (PCR) to amplify DNA fragments; (4) electrophoresis to ascertain DNA "fingerprints;" and (5) STR analysis for determining genetic profiling. And it completes the entire process in only 25 minutes.

The instrument was developed primarily for law enforcement

applications, so the compact size (500 x 400 x 200 mm) is a nice feature. No price information was available at press time, so presumably it ain't cheap. **NV**

COURTESY OF NEC CORP.



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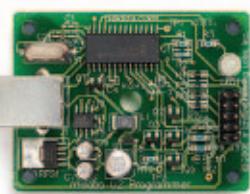
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RS232	2	2	2	2	2	4
PWM	3	6	6	3	6	12
ETC	-	-	RTC	-	-	-



PICAXE PRIMER

SHARPENING YOUR TOOLS OF CREATIVITY

■ BY RON HACKETT

IMPLEMENTING A SERIAL DATA LINK WITH THE IR MULTI-BOARD

IN THE TWO PREVIOUS INSTALLMENTS OF THE PRIMER, we constructed a stripboard version of the IR Multi-Board: an I/O module that can implement the full range of PICAXE IR capabilities. We also developed a simple IRMB-based object detection circuit for use in a robot or a home control system, as well as an interface that received and decoded the signals from a universal TV remote programmed to transmit the Sony IR Control (SIRC) protocol.

This month, we're going to resolve the problem of the missing key-presses that we had last time with our SIRC system and then move on to accomplishing our final goal for the IR Multi-Board: using two IRMB modules to implement a wireless serial data link for use in our projects. We'll be using the same setup we worked with last time, which consists of our standard 28X1 Master Processor circuit with one IRMB set up as a peripheral input device and a second IRMB installed on a mobile battery-powered breadboard for range testing. In addition, we'll make use again of a TV remote capable of transmitting in

the SIRC protocol. Our experiments will involve the following programs:

- HserinTestAll.bas
- HserinTestInt.bas
- RMBrxSIRC.bas
- IRMBserin.bas
- IRMBserout.bas

To save you the trouble of typing them into the Programming Editor, these programs are all contained in one ZIP file that is available on the *Nuts & Volts* website (www.nutsvolts.com). If you prefer, you can email me at Ron@RHackett.net and I'll send you the file. In order to make our discussion here easier to follow, it would be a good idea to get the

file and print out the five programs before you read much further.

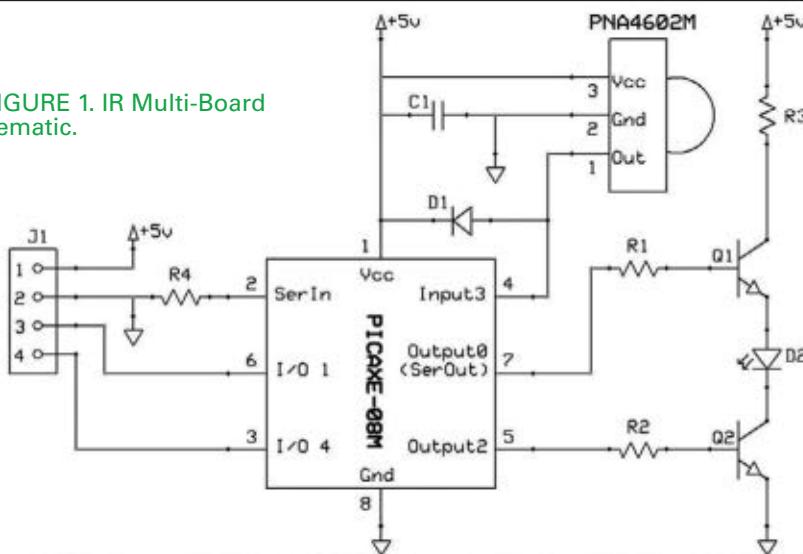
CAPTURING THE MISSING SIRC KEY-PRESSES

In our last experimental setup we programmed an IRMB to receive IR signals from a SIRC TV remote and relay the data to our 28X1 Master Processor. The 28X1's program was fairly simple and somewhat limited in that it was only capable of capturing a single key-press in the background; any additional key-presses that occurred during one blink of the LED were lost.

Our first setup this month will fix that problem. In order to do so, we will use the same physical setup with new (and improved) software. Output1 of the IRMB is again connected via a 4.7K resistor to input 7 (the hserin input) of the 28X1. Its program (RMBrxSIRC.bas) is essentially the same as the IRMB_Remote.bas software that we used last time. The improved functionality is implemented in the 28X1's HserinTestAll.bas software, which requires a brief explanation before we actually try it out.

To begin with, you may want to review the material we discussed last time about the 28X1's scratchpad

■ FIGURE 1. IR Multi-Board schematic.



memory and the three built-in variables available for use with it (hserinflag, hserptr, and ptr). As we mentioned, the scratchpad contains 128 locations, so there's plenty of room to capture all our SIRC remote key-presses. (Actually, the capturing of the serial input data occurs automatically in the background.)

Even in our previous setup, all the data was automatically stored in the 28X1's scratchpad; we just didn't access it. In order to be able to do so, we need to understand a bit about how the two pointer variables (hserptr and ptr) function. Essentially, hserptr can be thought of as a "write" pointer and ptr can be thought of as a "read" pointer.

Hserptr always contains the address of the scratchpad location in which the next received byte will be stored. When the 28X1 is set up for background serial receive, hserptr is automatically initialized to 0 so the first byte received is stored in location 0 of the scratchpad. Hserptr is then automatically incremented to 1 in preparation for the reception of the next byte. In this way, once we have issued the appropriate setup command ("hsersetup B1200_4, %01"), up to 128 bytes can be automatically stored in the scratchpad without our having to do anything else.

Retrieving the data is a little more involved and requires an understanding of the ptr pointer and of a concept called "indirect addressing." If you have done any assembly language programming, you're probably already familiar with indirect addressing; if not, here goes! If ptr = 0 and we write "sertxd (ptr)" a value of 0 would be sent to the terminal window. This is usually referred to as "direct" addressing and is something with which we are all familiar. In contrast, "indirect" addressing (which is often signified with the use of the "@" symbol) functions as follows: If ptr = 0 and we write "sertxd (@ptr)" then the **contents** of scratchpad location 0 (not the value 0 itself) would be sent to the terminal window. Therefore, @ptr is said to "point to" the value we want. It is a little confusing at first, but it's an

extremely powerful concept that actually saves us considerable programming effort. In order to clarify how all this works, let's take a look at how the "GetNewData" subroutine functions in the "HserinTestAll.bas" program. To make it easier to understand the following discussion, open HserinTestAll.bas in the Programming Editor and/or print out a copy. As you can see, the GetNewData subroutine is called once each time through the main programming loop. Since the LED is on for five seconds and off for one second, there's enough time for several keys to have been pressed on the remote before the GetNewData subroutine is called. Since the program has already been set up for background serial receive ("hsersetup B1200_4, %01), all the key-presses have been captured in the scratchpad while the LED was blinking. The function of the GetNewData subroutine is to access all the data that has been captured during the previous blink. If no key has been pressed during any one pass through the loop, then hserinflag is still 0 and GetNewData isn't called that time around.

Let's take a look at how GetNewData accomplishes its task. To understand the first statement ("lastDataLoc = hserptr - 1"), remember that hserptr always automatically points to the location in which the next byte will be stored so "hserptr - 1" is the location in which the last received byte has already been stored. Since the background storage always starts at location 0, we have both limits that we need for a simple for...next loop.

Each time through the loop the value of ptr is appropriately updated and the "sertxd (@ptr)" statement indirectly accesses the next stored value pointed to by ptr and sends it to the terminal window for display. The final three statements before returning from the subroutine simply re-initialize the three scratchpad variables so that the background storage will again begin at location 0 the next time through the main loop.

	8 Chars X 2 Lines	16 Chars X 2 Lines
No BackLight	HDM08216H-3-S00S	HDM16216H-5-S00S
BackLight	HDM08216L-3-L30S	HDM16216L-5-E30S

■ FIGURE 2. Hantronix LCD displays for upcoming projects.

That's enough theory for now – let's see how all this works in practice. As we mentioned earlier, the physical setup is identical to the one we used last time so all you need to do is download IRMBxSIRC.bas to your IRMB peripheral and HserinTestAll.bas to your 28X1 Master Processor. You may have already discovered that it's a good idea to download the two programs in that order because it leaves the Terminal Window open for the 28X1 to use.

Also, don't forget that most (if not all) TV remotes repeat their key-press data fairly quickly; any extra data you see displayed probably comes from holding down a button a little too long. So, fire up your system and see if you can capture every key-press you make.

ESTABLISHING A SERIAL DATA LINK

Once you can successfully display all the IR data received by the system, we're ready to move on to our goal of establishing an IR serial data link. To keep things reasonably simple, we're going to focus on a one-way link but the same principles could be used to develop a two-way link, as well. This time around, we're going to shift from using the SIRC protocol to the standard serial protocol. Of course, the main advantage of this approach is that we will be able to transmit and receive the full ASCII character set which can be very useful in a wide range of projects.

There's nothing new in the hardware we will be using. On the receiving end of the link, we'll use the same setup we just used in our SIRC approach while data transmission will be carried out by the same battery-powered IRMB setup we used in the previous installment of the Primer. This time, of course, we'll need three pieces of software for the three processors



involved. Fortunately, the 28X1's program (HserinTestAll.bas) remains the same; our peripheral IRMB (the one directly connected to the 28X1) will be running "IRMBserin.bas" and the remote (battery-powered) IRMB will use the "IRMBserout.bas" program. Before you download all the software and actually get to play with the system, there is one small theoretical point we need to discuss. (You didn't think you were going to escape this, did you?)

The ability to transmit and receive IR serial data is the IRMB's most powerful feature, but it does introduce a little complication or – more accurately – a bit of a paradox. Let's begin with the receiving end of the link which is the more straightforward of the two modules. You may remember that the Panasonic PNA4602 IR receiver is an "active-low" device, which means that its output idles in a high state and whenever data is received the output contains a sequence of low pulses. As a result, the 4602 outputs "True" serial data that, by definition, idles high (see the documentation for the serin command in Part II of the Manual). If you look at the IRMBserin.bas file, you will see that its serial input is True. So is its output to the 28X1, because the hserin command also requires True data. On the remote transmitting end of the data link, it's a little more complicated. The transmission of IR serial data involves two of the 08M outputs simultaneously because we need to modulate a 38 kHz carrier wave with the serial data so that it can be detected and demodulated by the 4602 on the other end of the link. If you look at Figure 1 (which presents the same IRMB schematic that we have seen before), you can see how its 38 kHz PWM carrier wave (output 2) is modulated by the serial output from output 0. When output 0 is high, the carrier wave is transmitted by the IR LED (D2); when output 0 is low, Q1 is turned off and the IR LED is not powered at all.

Another way of saying the same thing is that the output of the IR LED is idling when the serout line is low, i.e., the circuit is producing "inverted"

(N) serial output. All this seems clear unless you start to think too much about the fact that we are transmitting inverted serial data and seem to be receiving True serial data, which seems like a paradox or even a mistake. However, it all works because the PNA4602 is an active low device that, in effect, inverts the inverted data.

Now that you have suffered through another bit of theory, we're ready to have fun! Download the programs to their respective processors. Since the 28X1's terminal window will no longer be visible, you can either re-download its program as the last step or simply click on the 28X1 program (HserinTestAll.bas) and select "Terminal" under the "PICAXE" menu. If everything is functioning properly, you should see "Fee, fie, foe, fum!" repetitively appearing in the Terminal Window. If not, download the programs again to be sure you have each one installed in the correct processor. You may notice that one or two characters are frequently lost between each transmission block. This is due to the fact that the for...next loop in the GetNewData subroutine of the 28X1's program has so much data to send to the Terminal Window that one or two characters may be received in the background while it's busy outputting the data. Then, when the subroutine resets the scratchpad variables before returning to the main program, that data is effectively lost. The moral of the story is that this approach only works for small strings of data. If you need to transmit larger data strings (like Fee, fie, foe, fum!), a different approach is required. One possibility is to utilize the PICAXE's capability of responding to an external interrupt.

USING PICAXE INTERRUPTS

At this point, I can almost hear you muttering "Here we go again – another long-winded theoretical treatise!" Well, you may be right, but interrupts can be so powerful and useful in a program that I hope you will decide they are worth the effort they require. In fact,

using an interrupt can actually make a program easier to write and to understand, so here comes the wind ...

All current PICAXE processors (even the little 08M) have some form of interrupt capability (see the "setint" command documentation), but the X1 chips are the first PICAXEs that can be interrupted whenever a serial data byte is received in the background. Before we get into the details of how this is accomplished on the 28X1, we need to clarify exactly what's involved in an interrupt.

Normally, a program proceeds in a very predictable fashion, either sequentially from one command to the next or in a preprogrammed pattern of jumps, branches, and/or loops specified by the code. The problem with this type of structure is that it can't immediately respond to changes in inputs as they occur. For example, you might repeatedly press a push-button to get your program's attention, but it won't respond until it happens to be executing the code that reads the button presses. If it takes the program a couple of seconds to get to that point, you'll just have to wait. Even worse, your program may execute the relevant code in the fraction of a second between two of your frantic button-presses and ignore you altogether!

An interrupt subroutine solves this problem as follows: In the beginning of your program, you specify the input condition(s) that you want to trigger the interrupt. (We'll get to exactly how you do that shortly.) At the end of your program, you place your interrupt subroutine (which must begin with the label "interrupt:" and end with a "return" statement). The interrupt code specifies the action you want to take place in response to the input condition(s), e.g., the pushbutton is pressed and pulls input1 high.

No matter what your program happens to be doing at the time, the instant the button is pressed the program executes the interrupt subroutine code and then returns to what it was doing when the interrupt occurred. More specifically, it returns to the very next instruction it was about to execute when it was

interrupted. (We'll discuss this point in a little more detail later, as well.)

The only complicated part of all this is how you specify the input condition(s) that you want to trigger the interrupt. Since the setint command is a little simpler than the setintflags command, let's use it for our first example. The full syntax is "setint input, mask" where input refers to the desired input condition(s) and mask refers to (what else?) the mask. So, if your pushbutton is on input1 and pressing it makes the input high, you want the "input" parameter to equal "%00000010" — remember, the "%" indicates binary data and, in this context, that's easier to understand than a decimal number would be because the "1" in the bit1 position makes it clear that this is the input in which we are interested. However, without the mask we would be saying that we want input1 to be high and all the other inputs to be low, which is not what we mean and might never occur anyway. The mask solves this dilemma as follows: If you want a specific bit to be included in the input specification, place a "1" in the corresponding bit position of the mask; if you want to ignore a bit, place a "0" in the corresponding bit position of the mask. So, in our example, the complete command would be "setint %00000010, %00000010" — the second parameter (mask) says "just check input1 and ignore all the others" and the first parameter (input) says "whenever input1 is high, execute the interrupt code." You can also set up an interrupt to respond to multiple input specifications, but we're going to keep it (relatively) simple for now.

Whenever an interrupt routine is executed, the interrupt is immediately disabled. If this weren't the case and we pressed the button for even a fraction of a second, the interrupt would interrupt itself dozens of times — not usually what you want to happen (but see the documentation for an example of what to do when that is exactly what you do want to happen). However, since you probably want the interrupt to occur again on the next button-press, you

need to re-enable the interrupt by re-issuing the same setint command just before you return from the interrupt subroutine.

Once you have a fairly clear understanding of how PICAXE interrupts function, we're ready to move on to the setintflags command, which is the one we're going to use to retrieve the serial data that is automatically being received from the IRMB. The X1 chips contain a

built-in system "flags" byte and bit5 of this byte is the "hserflag" — it usually equals 0 but whenever a serial byte is received on the "ser rx" pin (pin 18 on the 28X1), hserflag is immediately set to 1. We can use the setintflags command to trigger an interrupt whenever this transition occurs. The complete syntax is "setintflags flags, mask" and it functions very similarly to the setint command. Since we want to trigger an interrupt

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immediately whenever a serial byte has been received (i.e., whenever the hserflag is automatically set to 1), the complete command we need is "set intflags %00100000, %00100000."

Similarly to the setint command discussed earlier, the second parameter (mask) says "just check bit5 of the flags (hserflag) and ignore all the others" and the first parameter (flags) says "whenever bit5 (hserflag) is high, execute the interrupt code." I know this has been a considerable amount of detail to wade through, but these are powerful commands and worth the effort.

Now let's turn our attention to the HserinTestInt.bas program that you downloaded earlier to see how we are going to implement our interrupt. The main program is very similar to that of the HserinTestAll.bas that we worked with earlier. The first major difference is the "setintflags" command that we just discussed. Once that command is executed, the remainder of the main program is an infinite "do...loop" that simply blinks an LED interminably. Next, we have the interrupt subroutine that, as you can see, is actually much simpler than the GetNewData subroutine of the earlier program.

We don't need to use pointers at all (because the interrupt only processes one received byte at a time) and the received byte is always stored in location 0 (because we reset the scratchpad variables each time before exiting the interrupt routine), which means that we can again use a simple "get" statement to retrieve the byte each time. Finally, before exiting the interrupt routine, we re-enable the interrupt so that the next byte will also be captured. The only other aspect of the program that requires explanation is the "myDelay" subroutine. I know it looks a little strange, and you're probably wondering why I didn't just use a "pause 500" command after the "high LED" and "low LED" commands in the main loop. In fact, that's exactly what I did do in my first attempt at this program.

The documentation for the setintflags command states that the "flags byte is checked between execution of each command line in the program, between each note of a tune

command, and continuously during any pause command" so I assumed that a pause command (but not a wait command) should work fine. However, with "pause 500" in each of those places, the LED blinked so rapidly that it appeared as if the pause commands were being ignored.

I finally figured out what was happening. Apparently, each time that the program was interrupted it didn't resume execution in the middle of the interrupted pause command; rather, it went on to the next command in the program, effectively truncating each pause and blinking the LED at a much too rapid pace. The solution of replacing each longer pause with a loop of much shorter pauses restored the LED's sanity, which supports my original interpretation of the problem.

Download the HserinTestInt.bas program to the 28X1 (the two IRMB programs remain the same) and try it; since the interrupt subroutine executes so quickly, this approach solves the problem of the occasional missing bytes that we saw earlier. The "pause 100" command in the IRMB_Serout.bas program slows things down more than enough for the interrupt routine to keep up with the data rate.

You may want to experiment with shortening that pause, but when I tried to do so I began to get some transmission errors. However, I think that the errors were caused by IRMBserin.bas not being able to keep up, not by the 28X1's interrupt routine. In any case, the current rate of transmission seems fast enough and is reliable at a distance of at least 20 feet, so I consider it adequate for my purposes. As you can see, the IR Multi-Board provides a powerful and flexible modular approach to the design of IR-based I/O circuits. Once we have covered several of the other devices on our list of I/O modules for our Master Processor board, we'll probably find a use for the IRMB in our Data Collection system. In the meantime, I'm sure you will also find the IRMB to be a helpful addition to some of your own projects. If you develop an interesting IRMB application, I would love to hear about it.

LET'S TAKE A BREAK!

The IR Multi-Board turned out to be more powerful than I realized it would be when I first began its development, but the explanations of the IRMB's various functions also have become more involved than I anticipated at the start of this three-part series. We've all been working fairly hard and we deserve a break! So, in the next installment of the Primer we're going to turn our attention to interfacing our Master Processor with various inexpensive LCD displays based on the Hitachi HD44780 controller (for more info, see "Getting Started with PICAXE Microcontrollers, Part 2" in the February 2007 issue of *Nuts & Volts*).

These displays are easy to work with and they can be extremely helpful in a variety of projects. We will be focusing on four specific Hantronix displays (see Figure 2) that I have chosen because they are inexpensive (ranging from \$5 to \$10) and have pinouts that are fairly easy to adapt to the construction of stripboard circuits. All of them are available at www.Mouser.com; go to their site and enter the Hantronix part number from Figure 2 to get pricing information and to download the datasheets.

We will be developing two types of stripboard circuits for each of the display sizes (16x2 and 8x2). Our first stripboard projects will simplify the interface between our Master Processor board and the parallel displays and our second approach will use a PICAXE-14M to convert the parallel displays to stand-alone serial peripherals for use with our Master Processor (or any other project you may have in mind). You may already have one or two small HD44780-based displays on hand that will also work with the circuits we will be developing.

For the 16x2 displays, the main requirement is that the 14 or 16 pin connector be along the top of the board. This arrangement makes the stripboard layout much simpler than what is required to accommodate a connector on the bottom edge of the display. So, before the next installment of the Primer arrives, you may want to round up a couple of suitable LCD displays and stripboards for our upcoming projects. **NV**

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APC # 50.4056.B. Bright red 12Vdc LED bulb assembly. Bayonet base fits standard 1156 socket. Fits turn signal lights, stop lights and tail lights. According to the package, the bulb is intended for off road or show purpose only. Not intended for regular driving condition.

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Perfect for small appliances and breadboard projects. Provides 3 / 4.5 / 6 / 7.5 / 9 or 12 Vdc, and it's regulated, so the voltage doesn't fluctuate when the load varies. Includes twelve of the most popular power connectors. UL.

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One of the loudest, most annoying piezoelectric sirens we have ever heard. High-pitched 100 db warble tone strongly encourages intruders to leave. Designed for 12Vdc, 200mA operation. Operates 6-12Vdc. Compact - only 2.27" long x 1.69" x 1.53". Metal mounting bracket. 6" wire leads. CAT# ES-11

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30 second voice recorder. 5.50" high. Operates on 2 AAA batteries (included).

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Red and black lead set with banana plug on one end and mini-grabbers on other end. 36" long. Mini-hooks provide a firm, insulated connection to small terminals and wires in high-density areas.

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Red / black. 0.75" centers.

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8" cord. Mating 2-conductor weather-resistant connectors on each end.

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40MM 12VDC FAN WITH COPPER HEATSINK

CoolerMaster # EEP-N41CS. 12Vdc fan and copper heatsink for MiniATX, EmbATX board. CPU type: Intel Pentium M/ Celeron M, 478 pin socket (Micro-FCPGA)

Fan Specs:

12Vdc, 0.10A.

40 x 40 x 10mm

Speed: 5,500 RPM

Airflow: 5.3 CFM

Dual Ball Bearing

Noise Level: 25 dBA

Connector: 3 Pins



Heat Sink: Copper Base + Copper Stacked Fin. Overall Dimensions: 50 x 50 x 40 mm

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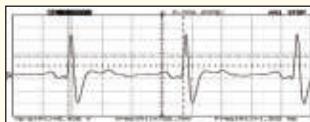
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Valentine's Day Goodies!

Electrocardiogram ECG Heart Monitor

- ✓ Visible and audible display of your heart rhythm!
- ✓ Bright LED "Beat" indicator for easy viewing!
- ✓ Re-usable hospital grade sensors included!
- ✓ Monitor output for professional scope display
- ✓ Simple and safe 9V battery operation



February is the month for Valentine's Day, and what a great time to think of your heart! Not how many times it's been broken, not how many times it's fallen head over heels in love, but how it actually works... and how it's doing these days!

Use the ECG1C to astound your physician with your knowledge of ECG/EKG systems. Enjoy learning about the inner workings of the heart while, at the same time, covering the stage-by-stage electronic circuit theory used in the kit to monitor it. The three probe wire pick-ups allow for easy application and experimentation without the cumbersome harness normally associated with ECG monitors. The documentation with ECG1C covers everything from the circuit description of the kit to the circuit description of the heart! Multiple "beat" indicators include a bright front panel LED that flashes with the actions of the heart along with an adjustable level audio speaker output that supports both mono and stereo hook-ups. In addition a monitor output is provided to connect to any standard oscilloscope to view the traditional style ECG/EKG waveforms just like you see on ER... or in the ER! See the display above? That's one of our engineers, hooked up to the ECG1C after an engineering meeting!

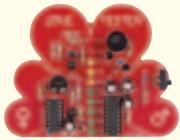
The fully adjustable gain control on the front panel allows the user to custom tune the differential signal picked up by the probes giving you a perfect reading and display every time! 10 hospital grade re-usable probe patches are included together with the matching custom case set shown. Additional patches are available in 10-packs. Operates on a standard 9VDC battery (not included) for safe and simple operation. Note, while the ECG1C professionally monitors and displays your heart rhythms and functions, it is intended for hobbyist usage only. If you experience any cardiac symptoms, seek proper medical help immediately!

ECG1C Electrocardiogram Heart Monitor Kit With Case & Patches
ECG1WT Electrocardiogram Heart Monitor, Factory Assembled & Tested
ECGP10 Electrocardiogram Re-Usable Probe Patches, 10-Pack

\$44.95
\$89.95
\$7.95

Electronic "Love Tester"

- ✓ 10 LED love scale display!
- ✓ Audible love level sound!
- ✓ Great party fun!
- ✓ Heart shaped PC board!



This uniquely shaped "Love Tester" is the ultimate gag for any couple! Designed to check your love life, each partner holds one end of the tester PCB at the appropriate male and female touch pads. Then they romantically join hands and watch the results on the love meter! 10 green, yellow, and red LEDs act like a scale, and just like the carnival when it hits the top they flash, indicating you're a red hot couple! There is also an audible alarm that changes with the "love level". Next time the party isn't going anywhere, bring this out, it's a riot!

Wide sensitivity range is compatible with all couples. Includes a built-in power on/off switch. Runs on a standard 9V battery. Measures 4.1" x 3.1" x .98".

MK149 Electronic Love Tester Kit \$16.95

LED Magic Message Wand

- ✓ Message floats in air!
- ✓ Fun at concerts & events!
- ✓ High visibility red LEDs
- ✓ Pre-programmed or custom messages



Use the "Magic Wand" to display your true feelings! Simply shake it back and forth and brilliant messages seem to appear in mid-air! Six high intensity LEDs are microprocessor controlled to display messages and graphics that are pre-programmed into the wand.

You can also custom program a message of your choice! From amazing your friends, making a statement at a concert, or simply telling your loved one how you feel, the message wand can't be beat!

Runs on two AAA batteries (not included), and the auto power off circuit gives you long battery life.

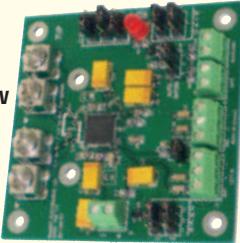
MK155 LED Magic Wand Kit \$12.95



Latest High-Tech Best Sellers!

Subminiature 40W Stereo Amplifier

- ✓ 2 independent 20W amplifiers in one SMT package!
- ✓ Super efficient Class D spread spectrum design!
- ✓ Built-in click and pop suppression!
- ✓ Selectable gain from +22dB to +36dB!
- ✓ Logic level mute and shutdown!
- ✓ Runs cool, no heat sink required!
- ✓ Built-in thermal protection!
- ✓ Runs on 10 to 18 VDC



The UAM4 is the big brother to the extremely popular UAM2. It uses the latest spread spectrum amplifier technology to bring you clear, crisp, high-power audio without any of the heat which is normally associated with such an amplifier. Its extremely clean Class D design produces two independent 20 watt outputs! This can also be bridged to an extremely efficient (87%) single channel (mono) 40 watt amplifier.

And at 40 watts, you're probably already wondering about the heatsink requirements to dissipate the heat, right? Stop wondering, there's no heat, so there is no heatsink required! And all that power is generated in a single SMT device the size of your thumbnail on a small 2 1/2" square board!

The high impedance input is designed to use your choice of either a balanced line input or an unbalanced signal source using easy to connect Euro terminal blocks. Logic connections to ground are also provided to mute and/or shut down the amplifier. You can also enable the built-in over temperature signal to activate one of these controls automatically! Easy to use board jumpers offer selectable gain of +22dB, +25dB, +29.5dB or +36dB to match your input levels. Board jumpers also enable protection and shutdown options as well as stereo/mono/bridge mode. The amplifier also features built-in click and pop suppression to protect not only your ears and sanity, but your speakers and equipment!

Power input for maximum rated output is 18VDC at 2.64A. Input voltage can be reduced to a minimum of 10VDC while maintaining the same high efficiency operation with reduced output power. If you're looking for an incredible stand-alone stereo (or mono) amplifier to build into your equipment, vehicle, speakers, or application, the UAM4 is the latest and the greatest!

UAM4 Subminiature 40W Amp Kit \$69.95

Retro Nixie Tube Clocks



- ✓ .7" bright orange Nixie display!
- ✓ 12/24 hour soft-fade display!
- ✓ Today's technology with yesterday's display!
- ✓ Custom hand-made wooden base!
- ✓ The ultimate conversation piece!

The Nixie tube made its debut in 1954 and became the standard in high-end test and military equipment. We brought it back in 2008 in one of the neatest digital clocks available today!

It features six IN14 Nixie tubes mounted in a beautiful hand crafted and hand rubbed Teak and Maple base. Advanced features include 12/24 hour format, brightness control, soft fade out, and auto-dim for selected windows of time. Runs on 12VDC with included AC power supply and utilizes a crystal time base accurate to 20ppm. You will be mesmerized watching the bright orange glow! Available in kit form or factory assembled

IN14TM Retro Nixie Clock Kit \$329.95
IN14TMW Retro Nixie Clock Asmb \$369.95

SMT LED Flashing Heart Display

- ✓ Alternating flashing!
- ✓ 6 super bright SMT LEDs!
- ✓ Learn all about SMT!
- ✓ Definitely gets her attention!



This cute little kit gives you a distinctive red display using 6 Surface Mount (SMT) LEDs. The PC board is in the shape of a red heart. The small size makes it perfect to be used as a badge or hanging pendant around your neck. Even better as an illuminated attention-getting heart to accompany a Valentines Day card!

Makes a great SMT learning kit to bring you into the world of SMT technology, design, and hands-on soldering and troubleshooting. Don't worry, extra SMT parts are included just in case you lose or damage any! Runs on a small CR2025 or CR2032 button cell (not included). Measures 1.9" x 1.7" x .3".

MK144 SMT LED Flashing Heart Kit \$11.95

Davis OBDII CarChip Pro

The incredible OBDII plug-in monitor that has everyone talking! Once plugged into your vehicle it monitors up to 300 hours of trip data, from speed, braking, acceleration, RPM and a whole lot more. Reads and resets your check engine light, and more!

8226 CarChip Pro OBDII Monitor \$99.95

LED Blinky

Our #1 Mini-Kit for over 35 years! Alternately flashes two jumbo red LED's. Great for signs, name badges, model railroading, and more. Used throughout the world as the first learning kit for students young and old! Great solder practice kit. Runs on 3-15 VDC.

BL1 LED Blinky Kit \$7.95

Universal Timer

Build a time delay, keep something on for a preset time, provide clock pulses or provide an audio tone, all using the versatile 555 timer chip! Comes with circuit theory and a lots of application ideas and schematics to help you learn the 555 timer. 5-15VDC.

UT5 Universal Timer Kit \$9.95

RF Preamplifier

The famous RF preamp that's been written up in the radio & electronics magazines! This super broadband preamp covers 100 KHz to 1000 MHz! Unconditionally stable gain is greater than 16dB while noise is less than 4dB! 50-75 ohm input. Runs on 12-15 VDC.

SA7 RF Preamp Kit \$19.95

Mad Blaster Warble Alarm

If you need to simply get attention, the "Mad Blaster" is the answer, producing a LOUD ear shattering raucous racket! Super for car and home alarms as well. Drives any speaker. Runs on 9-12VDC.

MB1 Mad Blaster Warble Alarm Kit \$9.95

Water Sensor Alarm

This little \$8 kit can really "bail you out"! Simply mount the alarm where you want to detect water level problems (sump pump!). When the water touches the contacts the alarm goes off! Sensor can even be remotely located. Runs on a standard 9V battery.

MK108 Water Sensor Alarm Kit \$6.95

Air Blasting Ion Generator

Generates negative ions along with a hefty blast of fresh air, all without any noise! The steady state DC voltage generates 7.5kV DC negative at 400uA, and that's LOTS of ions! Includes 7 wind tubes for max air! Runs on 12-15VDC.

IG7 Ion Generator Kit \$64.95

IC AM/FM Radio Lab

Learn all about AM/FM radio theory, IC theory, and end up with a high quality radio! Extensive step-by-step instructions guide you through theory, parts descriptions, and the hows and whys of IC design. Runs on a standard 9V battery.

AMFM108K AM/FM IC Radio Lab Kit \$34.95

Practice Guitar Amp & DI

Practice your guitar without driving your family or neighbors nuts! Works with any electric, acoustic-electric, or bass guitar. Plug your MP3 player into the aux input and practice to your favorite music! Drives standard headphones and also works as a great DI!

PGA1 Personal Practice Guitar Amp Kit \$64.95

Passive Aircraft Monitor

The hit of the decade! Our patented receiver hears the entire aircraft band without any tuning! Passive design has no LO, therefore can be used on board aircraft! Perfect for airshows, hears the active traffic as it happens! Available kit or factory assembled.

ABM1 Passive Aircraft Rcvr Kit \$89.95

Laser Light Show

Just like the big concerts, you can impress your friends with your own laser light show! Audio input modulates the laser display to your favorite music! Adjustable pattern & speed. Runs on 6-12VDC.

LS1 Laser Light Show Kit \$49.95

Electronic Siren

Exactly duplicates the upward and downward wail of a police siren. Switch closure produces upward wail, releasing it makes it return downward. Produces a loud 5W output, and will drive any speaker! Horn speakers sound the best! Runs on 6-12VDC.

SM3 Electronic Siren Kit \$7.95

Voice Activated Switch

Voice activated (VOX) provides a switched output when it hears a sound. Great for a hands free PTT switch or to turn on a recorder or light! Directly switches relays or low voltage loads up to 100mA. Runs on 6-12 VDC.

VS1 Voice Switch Kit \$9.95

Tone Encoder/Decoder

Encodes OR decodes any tone 40 Hz to 5KHz! Add a small cap and it will go as low as 10 Hz! Tunable with a precision 20 turn pot. Great for sub-audible "CTS" tone squelch encoders or decoders. Drives any low voltage load up to 100mA. Runs on 5-12 VDC.

TD1 Encoder/Decoder Kit \$9.95

Touch Switch

Touch on, touch off, or momentary touch hold, it's your choice with this little kit! Uses CMOS technology. Actually includes TWO totally separate touch circuits on the board! Drives any low voltage load up to 100mA. Runs on 6-12 VDC.

TS1 Touch Switch Kit \$9.95

Walking Electronic Bug

Built around a pair of subminiature cell phone motors, this bug wanders around looking for things to bump into! Sensors below his LED eyes sense proximity and make him turn away! Steer him with flashlights too! Runs on two "N" batteries.

WEB1 Walking Bug Kit \$29.95

DTMF Encoder Decoder

Decodes standard Touch Tones from telephones, radio, or any audio source. Detects and decodes any single digit and provides a closure to ground up to 20mA. Great for remote tone control. Runs on 5VDC.

TT7 DTMF Encode/Decode Kit \$24.95

Super Snoop Amplifier

Super sensitive amplifier that will pick up a pin drop at 15 feet! Full 2 watt output drives any speaker for a great sound. Makes a great "big ear" microphone to listen to the "wildlife" both in the field and in the city! Runs on 6-15 VDC.

BN9 Super Snoop Amp Kit \$9.95

RF Actuated Relay

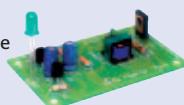
Just what you need when adding a preamp or power amp in line with an antenna! Auto senses RF and closes an on-board DPDT relay that's good to UHF at 100W! Also great to protect expensive RF test equipment. Senses as low as 50mW!

RFS1 RF Actuated Relay Kit \$19.95

HV Plasma Generator

Generate 2" sparks to a handheld screwdriver! Light fluorescent tubes without wires! This plasma generator creates up to 25kV at 20kHz from a solid state circuit! Build plasma bulbs from regular bulbs and more! Runs on 16VAC or 5-24VDC.

PG13 HV Plasma Generator Kit \$64.95

Tickle-Stick Shocker

The kit has a pulsing 80 volt tickle output and a mischievous blinking LED. And who can resist a blinking light and an unlabeled switch? Great fun for your desk, "Hey, I told you not to touch!" Runs on 3-6 VDC.

TS4 Tickle Stick Kit \$12.95

Stereo Ear Super Amplifier

Ultra high gain amp boosts audio 50 times and it does it in stereo with its dual directional stereo microphones! Just plug in your standard earphone or headset and point towards the source. Great stereo separation besides! Runs on 3 AAA batteries.

MK136 Stereo Ear Amplifier Kit \$9.95

3-In-1 Multifunction Lab

The handiest item for your bench! Includes a RoHS compliant temp controlled soldering station, digital multimeter, and a regulated lab power supply! All in one small unit for your bench! It can't be beat!

LAB1U 3-In1 Multifunction Solder Lab \$129.95

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■ BY LOUIS E. FRENZEL W5LEF

CONVERTING TO DIGITAL TV

Fun with converter boxes and antennas.

SURELY YOU HAVE HEARD THAT AS OF FEBRUARY 17, all analog TV signals will be shut down and new digital TV signals will be the only ones broadcasted. That means that if you do not have a digital TV set or you do not subscribe to a cable or satellite TV service, you won't be getting over the air (OTA) TV signals. Most of you (over 80%) probably already have cable or satellite TV so you won't notice any difference. If you are a diehard free OTA TV advocate, however, you will need a new digital TV set or a converter box.

TIME FOR A NEW TV

If you have been looking for an excuse to get a new TV, this is it. Your best bet is to go ahead and take the plunge. If you like TV and watch a lot, you can justify it. Most TV sets last a long time, and amortize over many years the expenditure is only a tiny part of your budget. My old 27 inch RCA set lasted 17 years before it blew on Thanksgiving last year. New sets are very reliable these days, so you can count on them lasting for a while and simultaneously enjoy the pleasures of a bigger, higher definition picture. You don't have to spend a fortune, either.

Not all DTV sets are high definition (HD), so you can get a reasonably

priced standard definition digital TV set (see the sidebar on DTV definitions) for less than \$400. Now is actually a great time to update to HDTV as prices for even the larger screens have dropped considerably. HDTV is a definite improvement over older analog TV, but if you are short on cash there is a low cost option: a converter box.

CONVERTER BOXES

Converter boxes are the lowest cost alternative for OTA TV. These boxes receive the DTV OTA signals and convert them to low resolution analog signals for presentation on your dated TV set. You can find converter boxes on sale at dozens of places

where you get TV sets or electronic accessories, such as Best Buy, Circuit City, RadioShack, Target, and Wal-Mart. You can buy them online, as well. Prices run between \$40 to \$70. Plus you can get a discount card from the government who is subsidizing the DTV conversion process. Each family is eligible for a maximum of two \$40 discount cards. Just go to the website for the National Telecommunications and Information Administration (NTIA) at www.ntia.doc.gov/dtvcoupon/ and sign up. It does take several weeks to get the card, so keep that in mind.

As for what box to buy, I don't have any specific recommendations. There are dozens of manufacturers and the products are pretty much all the same. The boxes are black and are approximately 9 x 6 x 2 inches in size. They have an antenna input connector and one or more outputs that go to the TV antenna input or the video/audio inputs on the TV set. All have a remote control and most include all the cables you need for connections. The connections are pretty simple and are described in detail in the included instruction manual. However, here are your choices in a nut shell. Figure 1 shows the back panel of my box.

- **Direct RF connection.** The

DTV DEFINITIONS

- **Standard Definition TV:** This is the version of DTV that is similar in resolution to regular analog TV. It uses 480 horizontal lines and either 704 or 640 pixels per line. The designation is 704 x 480 or 640 x 480. The aspect ratio (width by height proportions) is usually 4:3 but there is a wide screen 16:9 version. Scanning is usually interlaced (i) rather than progressive (p), and occurs at a rate of 30 frames per second (fps). SDTV is also called 480i.
- **Enhanced Definition TV:** This intermediate version is also available in 704 x 480 or 640 x 480 formats in either 4:3 or 16:9

aspect ratios. Scanning is usually progressive. Frame rates of 24, 30, and 60 fps are used in various applications. EDTV is called 480p. • **High Definition TV:** HD sets use either 720 or 1,080 horizontal lines with either 1,920 or 1,280 pixels per line. Scanning can be either interlaced or progressive at rates of 24, 30, or 60 fps. Newer 120 fps and even 240 fps versions are also available. Faster picture rates produce less smearing on action scenes, especially on LCD screens. The aspect ratio is 16:9. Over the air broadcast TV and DVDs use a 720 pixel x 480 line format. HDTV is usually called 1080p or 1080i. By the way, progressive scan gives greater resolution than interlaced.

antenna ties to the input F-connector and the output connects to the antenna F-connector on the TV set. (NOTE: An F-connector is just a 75 ohm coax cable connector. It is threaded and the solid wire of the coax is used as the center conductor of the connector.)

- S-video connection.** S-video is a slightly higher resolution video connection. It uses a special connector and cable. Most converter boxes have an S-video output if you need it. Normally, you have to hook up the audio separately with a pair of stereo audio cables with the usual red and white RCA phono type connectors.

- Composite video connection.** This is where you connect the video output (not the RF) from the converter box to the composite video input on the TV set (if it has one). This is usually done with a coax cable with RCA phone connectors (typically coded yellow). You also need the red and white RCA connectors and cables for the audio.

- Set the channel switch to either channel 3 or 4.** Your TV set should be set to the same channel. It used to be a problem which channel to select but today, either usually works fine. If you have any interference problems, just change the channel setting on the converter box and your TV set.

WHAT CHANNELS ARE INVOLVED?

Before you go any further, make sure you know what TV channels you watch and where they are located. You probably know their channel numbers but just make note that their digital signal will be on a new UHF channel. You will need to find out what these are. The best way to do this is to go to www.antennaweb.org. The site asks for your address, then comes back to you with a list of local stations you can get, their old analog channel numbers, and their new digital channel number. The listing also gives you the azimuth readings from your house to the TV station antenna so you can point it



■ FIGURE 1.Typical back panel of a DTV converter box. Note the smart antenna jack that is designed to attach to one of the newer amplified rotational indoor antennas. (And the Do Not Temper label! - Ed.)

properly if you have a compass.

Another good source of the digital and HD TV channels is www.antennasdirect.com. They list the major TV markets, the stations, and their new channel numbers. Most are in the UHF band but as it turns out, there are about 100 US stations that have their HDTV in the VHF bands. Check out the sidebar that shows the VHF and UHF channel frequency allocations. There used to be 69 UHF channels from 14 to 83. But in the 1980s, the FCC (Federal Communications Commission) took channels 70 to 83 (806 to 890 MHz) for the US cellular telephone band.

More recently, the TV bands also lost channels 52 to 69 (698 to 806 MHz) since there were very few TV stations in that spectrum. This is the 700 MHz band the FCC recently auctioned off for \$19.6 billion for an expansion of cellular telephone use and other wireless services. Today, the UHF channels are 14 to 51 only. That's okay though, because broadcasters can squeeze up to four complete digital HDTV signals into one of the old 6 MHz analog channels using data compression techniques. You will see the channels designated like 24.1, meaning that is the first channel of four digital signals for channel 24.

Actually, you can get by without knowing all the channel numbers as most of the converter boxes will scan for the digital stations in your area and make a list for you. It sets up a menu for you to select from with the remote control that comes with the

ABOUT SMART ANTENNAS

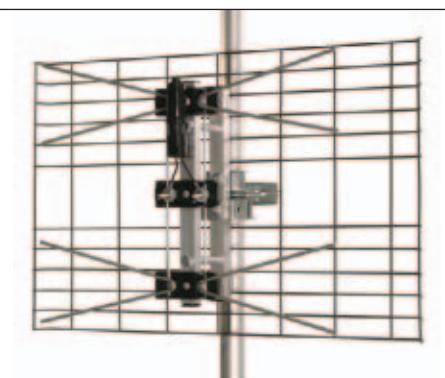
In Figure 1, there is a jack for a "smart antenna." A smart antenna is a new high-tech type of indoor antenna that is basically omnidirectional and self-adjusts to signal level. When connected to the converter box, it senses channel changes and then adjusts itself to pick up a signal. The internal mechanism is like having an antenna rotor since it scans the horizon for a signal then optimizes the signal level. There's no having to get off the couch to tweak the position of the rabbit ears or add the aluminum foil. If you are still using the old rabbit ears, just be aware that there have been some real upgrades to indoor antennas. Many are amplified to give even better reception. Check out the smart antennas next time you are in an electronics store.

converter box. Nevertheless, you should know the new channel numbers so you can get the right antenna.

Finally, let me say this. Follow the instructions in the manual you get with the converter box. Hook-up is relatively simple. What I found difficult is the complex remote control that comes with it. Over three quarters of my converter box manual is devoted to the remote control operation. (Not as bad as the complex three remotes for my new HDTV setup, but bad enough!)

ANTENNAS

This could be an entire article by itself! There are tons of choices and they all depend on your specific situation. There is no "one size fits all" antenna. Since TV is basically RF or radio, it is subject to all the rules of physics and oddities of radio wave propagation, not to mention the characteristics of your specific location. What you were using for



■ FIGURE 2. A standard bow tie configuration antenna with a mesh reflector that gives gain, as well as directionality.



SOURCES

Antennas Direct
www.antennasdirec.com
Antenna Web
www.antennaweb.org
DTVAnswers
www.dtvanswers.com
DTV Transition Federal Communications Commission
www.fcc.gov/dtv
National Telecommunications and Information Administration
www.ntia.doc.gov
www.dtv2009.gov

analog TV may or may not work for DTV. For DTV, you just have to experiment. Once you set up your converter box, try the antenna you have been using. Chances are that this antenna will work for DTV. Try it out before purchasing a new antenna.

If you have reception problems, a good next step is a new, improved indoor antenna. There are dozens to choose from, ranging in price anywhere from \$30 to \$80. Most of these are amplified antennas giving you the extra gain sometimes needed to make the digital signals strong enough. And don't forget that these indoor antennas are also directional. You have to rotate them to get the strongest signal.

There are a few indoor antennas called smart antennas that have built-in rotational capability and come with a remote control that lets you tweak the direction from the couch. Most are amplified and automatic. While these work well, you still have to position them so they can get maximum signal. Just play around with placement.

Reception of digital signals is really

TV CHANNEL FREQUENCIES

VHF — Channels 2-13.

Channels 2 to 6 (low band): 54 MHz to 88 MHz. Channels 7 to 13 (high band): 174 MHz to 216 MHz.

UHF — Channels 14-51: 470 to 698 MHz.

Note: Each channel is 6 MHz wide.

different from analog signals. Analog signals fade and get weaker, and the picture degrades slowly into a snowy mess. With digital signals, you either get the signal or not. In some cases, you will get the brief pixilation effect then zap — nothing. It's either a good picture or just black. You will need a little more signal strength with digital than with analog to get a picture. So, if you are out in the fringes of the station coverage, you may need an amplified antenna or an outdoor antenna. Most rabbit ears and indoor antennas are good for up to about 40 miles from the station. Just remember, these UHF signals hate going through walls, roofs, and trees. The higher frequencies are more easily absorbed by surrounding objects than VHF signals. Reflections are more common, as well. (There have been actual cases where a signal directly from the transmitter was blocked, but a strong signal was received from a reflection source like a water tower. Weird but true.)

You can get a good flat panel outdoor antenna for about \$50. It is unobtrusive in its white plastic case and is usually amplified. Just point it in the right direction, mount it, and enjoy (see Figure 2). The secret to a good outdoor antenna is to get it up as high

as you can. UHF signals are truly line of sight (LOS), so your antenna needs to "see" the TV station antenna as best it can. If your

local stations have different antenna locations, you may need a rotor to turn the antenna in the right direction. In most metro areas, the TV stations try to co-locate their antennas on one tower so your antenna orientation can be fixed. (That is not always the case, though.) Rotors can be a pain to set up, but do work well. For fringe reception beyond 40 miles, a bigger antenna array is needed. Figure 3 shows a couple of examples of high gain antennas. High gain implies high directionality so you will most likely need to pay closer attention to the orientation than you did before. Or, you will need the rotor.

One final thing about outdoor antennas. Many communities frown on outdoor antennas. Most home owner associations have covenants forbidding them. A few allow satellite TV dishes as they are small but a big TV antenna may be a real no-no. So check this out to see what is possible before you buy anything.

You could put the antenna in an attic, if you have one. Putting the antenna inside always attenuates the signal so get a high gain antenna with amplification to offset this.

One other thing is that at UHF frequencies, coax cable attenuation is far greater than the attenuation at VHF. What that means is you will lose more signal in the cable than you did before. So, keep it as short as possible, and use higher quality cable. For example, RG-6/U coax is 75 ohm cable like the more common RG-59/U but has far less attenuation. (That's why the cable TV companies use it exclusively.) Replace your old coax if it is more than a few years old.

FINAL THOUGHTS

You will probably have to experiment with the antenna situation to get a satisfactory picture. It is a whole new ball game with digital UHF signals, but there is a solution out there for you. Check out the options at your local electronics store. And remember, there is tons of great information on the Internet. Check out the list included here which gives you the best sources of additional information. And if all else fails, just sign up for cable or satellite TV. **NV**

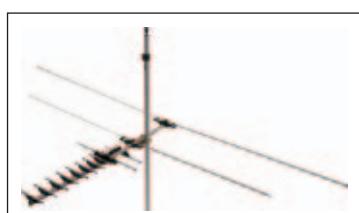


FIGURE 3. Two popular types of outdoor antennas that work with DTV. The first is a typical flat panel antenna. You can hardly tell it is an antenna at all. It does need to be positioned high and oriented for best reception. (Photo courtesy of Lacrosse and Antenna Web.) The second is the familiar Yagi configuration. The smaller elements are for the UHF channels. You will probably need a rotor if you watch more than one station and the stations are in different locations. (Photo courtesy of Antenna Web.)

WHAT'S UP:

Join us as we delve into the basics of electronics as applied to every day problems, like:

- CO₂ Laser Power Supply
- A Cycling Circuit
- LED Replacement of Bulbs

Q&A



■ WITH RUSSELL KINCAID

In this column, I answer questions about all aspects of electronics, including computer hardware, software, circuits, electronic theory, troubleshooting, and anything else of interest to the hobbyist. Feel free to participate with your questions, comments, or suggestions.

Send all questions and comments to:
Q&A@nutsvolts.com

ADJUSTABLE POWER SUPPLY, 0 TO 480 VDC

OI want to construct a cheap and reliable simple AC to DC power supply, adjustable from 0 to 480 VDC at 100 mA. I have a circuit (Figure 1) for one that goes to 330 VDC. What components and what values should I use for this circuit to bring the output up to 480 VDC? I also want to connect a 500V digital panel meter at the output.

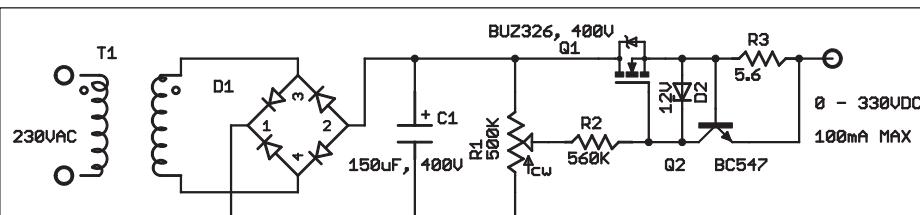
— **Theodore Karatzas**

the power dissipation in Q1. The power is 30 watts if you use the switch; 60 watts if you don't. When the output is below 300 volts, connect the drain to the 300 volt source. For outputs over 300 volts, connect the drain to the 600 volt source.

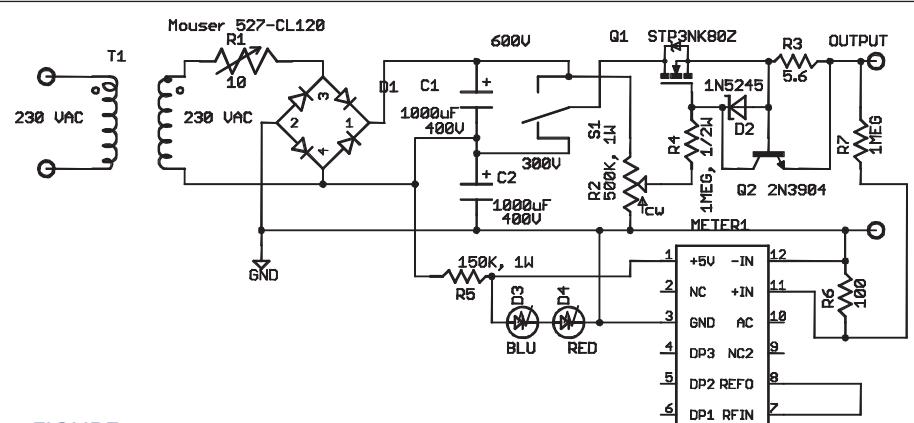
You want a digital voltmeter. That is quite easy, but you should be aware that some meters cannot measure a source that is common with the power supply and have to be battery powered. The meter I have chosen runs on 5 volts and has an onboard DC/DC inverter to produce the needed

-5V (Mouser PN 580-20LCD-0-5C; (www.mouser.com). A five volt zener (1N751) is soft and requires about 20 mA to be sure of getting five volts. Better regulation at lower power is obtained using LEDs. In this case, I used a red and a blue in series for five volts. The meter draws 400 µA so the LEDs will be dim, but you can still use them for power-on indication.

For very little added cost, you can have some regulation (see Figure 3). Move the 10 turn 500K pot to the output and connect to Q3 as shown. The lowest output voltage will be $V_{gs(on)}$ of Q3. Because V_{gs} is not

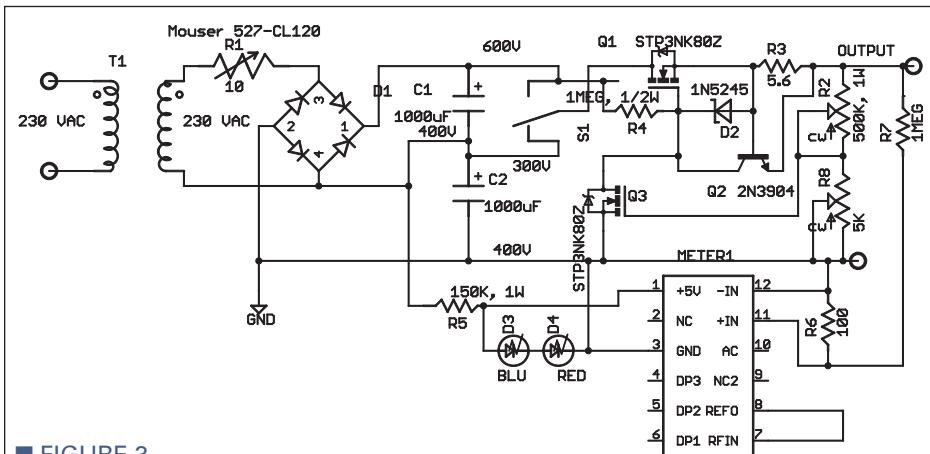


■ FIGURE 1



■ FIGURE 2

AI am sure you will want to use the 1:1 isolation transformer if possible; transformers are expensive. You can also use the bridge rectifier if the rating is greater than 600V. The circuit in Figure 2 is a voltage doubler. The two lower diodes in the bridge are doing nothing; if you are building the rectifier from discrete parts, you only need two diodes. The ripple is still 120 Hz because we are using both alternations of the input waveform. I have increased the filter cap from 150 µF to 1,000 µF because the lower value will produce five volts of ripple, which I think is excessive. Q2 is a current limiter which is a good thing to have because otherwise, accidental shorts at the output would cause Q1 to explode (I have blown up a few in my day). The switch at Q1 drain is to reduce



■ FIGURE 3

closely controlled, I made R8 a pot. To adjust R8, set R2 for maximum voltage and adjust R8 for 500 volts out.

AUDIO TO TTL CIRCUIT

O Is there a 5-6 VDC circuit which can convert audio input (from typical line input) to a TTL signal that can drive a transistor or a single LED – sort of a simple color organ?

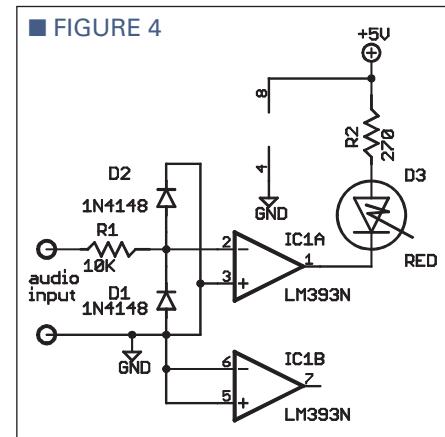
— Robert Christopher

A An LM393 comparator should do the job; check out Figure 4. The diodes are for input protection. I sometimes parallel the inputs and outputs of this dual comparator so I can pulse the laser and control the power output. I have been able to find all kinds of power supply plans

CO₂ LASER POWER SUPPLY QUESTION

Q I have been working on a CO₂ laser engraver/cutter project for a couple of months now. Although I didn't realize how little I understood when I started this project, I have managed to glean most of the knowledge I needed off the web. At this point, I have a working X/Y robot controlled by a PIC18F2550 that also monitors all of the safety features, coolant flow, hood open state, etc. However, I'm running into one major hurdle that I'm hoping you can help me with.

I need a power supply that can be controlled by my microcontroller so I can pulse the laser and control the power output. I have been able to



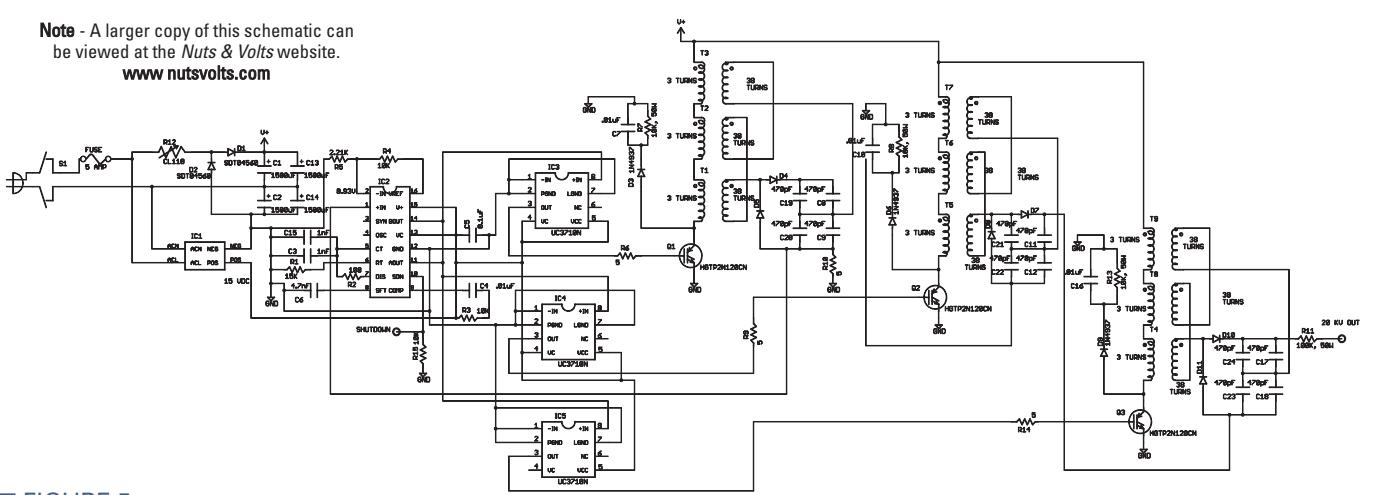
for CO₂ lasers but none of them give me the control I desire. If I understand what I have been reading, I need 20 KV and roughly 15 mA. The laser tube has a negative resistance so current control is critical. I'm a little fuzzy on this, but I guess it is the current that controls the actual laser power output, so a simple switching power supply does not work. The tube I am using is a 20W, sealed, DC excited laser tube.

Any help will be appreciated.

— Jeremy

A The negative resistance of the CO₂ laser is a control problem, so the solution is to put a positive resistance in series such that the net resistance is positive. My research indicates that the negative resistance runs -25K to -50K ohms. Putting 100K in series should guarantee positive net resistance of about 50K. The voltage

Note - A larger copy of this schematic can be viewed at the *Nuts & Volts* website.
www.nutsvolts.com



■ FIGURE 5

drop will be $100K * 15mA = 1,500$ VDC; the power dissipation will be 22.5 watts. The power from a 20KV supply at 15 mA is 300 watts. At 20 percent efficiency, the maximum power from the laser will be 55.5 watts.

The problem for me will be designing a 20KV power supply. Making a transformer with 20KV insulation is the problem; ordinary enameled magnet wire is good for 400 volts, as I recall. I finally hit upon using stacked pot cores. Magnetics, Inc., (PN SR-43019-UG) has a hole in the center that will accept a 3/16 bolt. There are several bobbins available for that core; I am recommending PN B3019-02 which has two sections. You can put the primary in one section and the secondary in the other.

The primary current peaks at about 10 amps, so use #16 wire. There are three turns; it will fit. The secondary has 38 turns and for 15 mA, #30 wire will work. I am expecting 7,000 volts in each of three secondaries, so that means 61 volts per turn; no problem there. Twenty-one turns will fill the first layer, then three mils of polyimide tape will insulate the second layer.

The circuit (Figure 5) shows three identical circuits with the secondaries connected in series. I did that to keep the drain voltage of the IGBT under 800 volts. I found that increasing the number of turns past a certain point caused the output to drop rather than increase. I don't know why this happens, but three transformers in three circuits works in simulation.

The circuit has an inrush current limiter (R12) to protect the diodes and fuse. The frequency is 20 kHz, set by C3, C15, and R1. I used two 1 nF caps because 2 nF NPO is hard to find. C6 provides a soft start after pin 8 is pulled low to shut down the supply. A logic high on pin 10 will shut down the supply immediately, and if held high more than 100 ms, soft start will occur.

20 KILOVOLT POWER SUPPLY PARTS LIST

■ FIGURE 6

PART	DESCRIPTION	PART NUMBER	SUPPLIER
■ IC1	15 volt PWM supply	418-CFM1003S	Mouse
■ R12	47Ω (current limiter)	527-CL80	Mouse
■ D1, D2	4A, 600V Schottky	726-SDT04560	Mouse
■ C1, C2, C13, C14	1500 µF, 200V electrolytic	5985-381-200V1500	Mouse
■ C3, C15	1 nF, 50V, 5%, NPO	140-CC501N102J-RC	Mouse
■ C4	0.01 µF, 50V, 10%, X7R	140-CC502B103K-RC	Mouse
■ C6	4.7 nF, 50V, 10%, X7R	140-CC501B472K-RC	Mouse
■ C5	0.1 µF, 50V, 10%, X7R	140-CC502B104K-RC	Mouse
■ C7, C10, C16	.01 µF, 2000V, +80-20%, Z5U	81-DEBE33D103ZA3B	Mouse
■ D3, D6, D9	1A, 1,000V, fast recovery	625-BA159-E3	Mouse
■ IC2	PWM IC, SG2525	511-SG2525AP	Mouse
■ R1	15K, 1%, 1/8W, SMD	290-15K-RC	Mouse
■ R2	100Ω, 1%, 1/8W, SMD	290-100-RC	Mouse
■ R3, R4, R15	10K, 1%, 1/8W, SMD	290-10K-RC	Mouse
■ R5	2.21K, 1%, 1/8W, SMD	290-2.21K-RC	Mouse
■ R6, R9, R14	5Ω, 1%, 1/8W, SMD	660-SR732BTTE5R11F	Mouse
■ C3, C15	1 nF, 50V, 5%, NPO	140-CC501N102J-RC	Mouse
■ C7, C10, C16	.01 µF, 1KV, 10%	75-564R30GASS10	Mouse
■ IC3, IC4, IC5	FET driver, UC3710N	595-UC3710N	Mouse
■ Q1, Q2, Q3	1,200V, 7A, IGBT	512-HGTP2N120CN	Mouse
■ D3, D6, D7	1,000V, 1A, fast rectifier	625-1N4937-E3/54	Mouse
■ R7, R8, R13	10K, 10%, 50W	71-RH50-10K	Mouse
■ T1-T9	Pot core	DP-43019-UG	Magnetics
	Bobbin	B3019-02	Magnetics
■ D4, D5, D7, D8, D10, D11	20 KV, 100 mA, 100 ns		eBay
■ C8, C9, C11, C12, C17-C24	470 pF, 6KV, Y5P, 10%	140-602P9-471K-RC	Mouse
■ R11	100K, 1%, 50W	71-RH50-100K	Mouse

The usual way to turn a laser beam on and off is by means of a Kerr cell which blocks the beam and allows the laser to run CW. I suppose you can achieve higher peak power without exceeding the rated average power of the laser by turning the high voltage on and off. C4 and R3 are a compensation RC to (hopefully) prevent oscillation. Any feedback system has a tendency to oscillate; if it happens here, just increase C4 until it stops.

I don't know of any place you can buy the pot cores in small quantities, but Magnetics is liberal with samples; so try that. I would make three stacks of three pot cores, rather than one stack of nine cores so you can put the transistor close to the primary. It is advisable to minimize the external primary inductance in order to minimize the spiking at the collector of the IGBT. Figure 6 is the parts list for this supply.

One final note: the output of this circuit is LETHAL so carefully consider

whether or not you feel comfortable with your assembly and test skills.

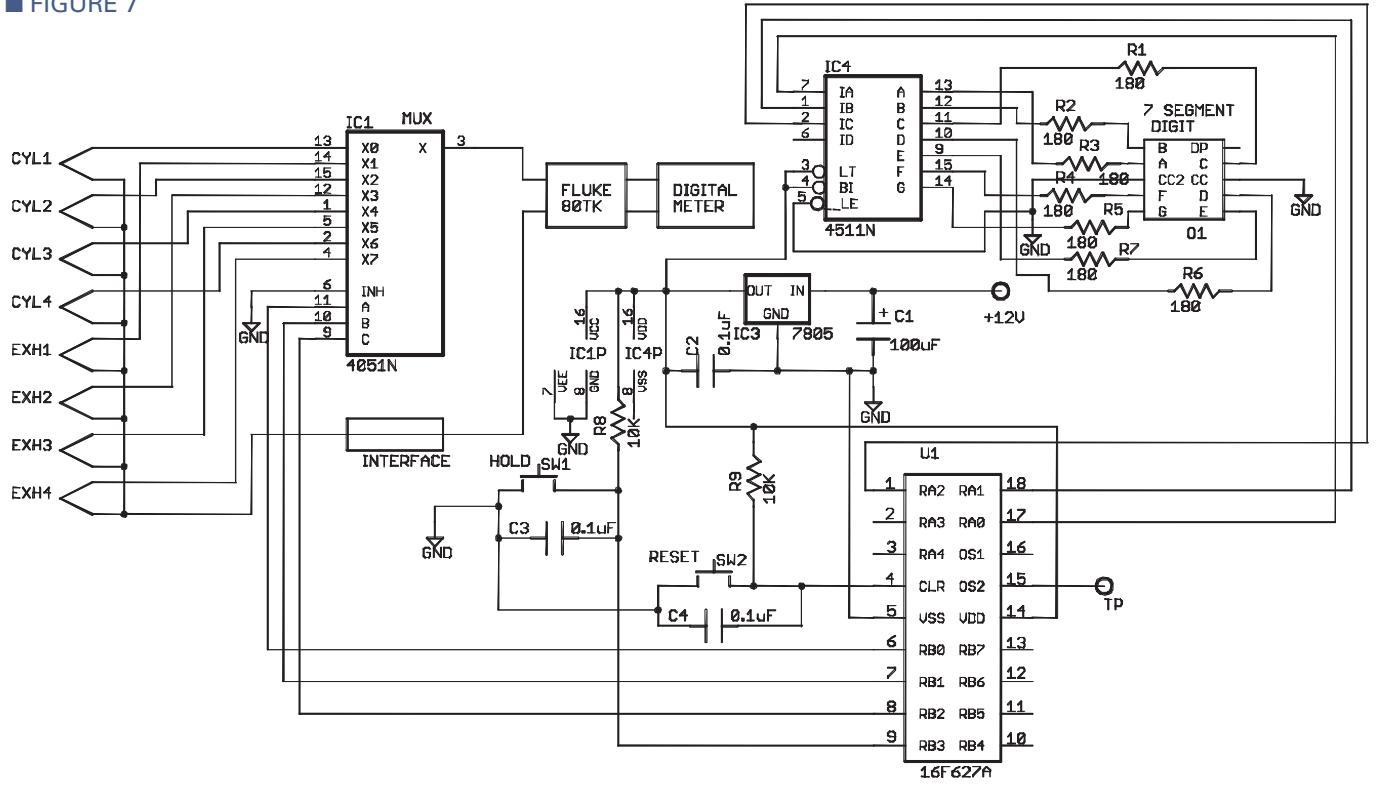
LED REPLACEMENT OF INCANDESCENT BULBS



Due to the high cost of electricity, I became interested in finding a way to use LEDs for general lighting purposes. In spite of replacing my incandescent bulbs with these so-called energy saving bulbs — which are being widely sold — I still pay too much for my electrical bills, influenced by the fuel price increases. Can you help me with a circuit where I can use LEDs that can have an illumination equivalent to a 100 watt incandescent bulb or a 40 watt fluorescent light tube? I don't want to use a transformer. I have several 5 mm white clear LEDs, each rated at 3.5 VDC and 10,000 mcd. The power supply is 240 VAC, 50/60 Hz. I would be most happy if you can provide me



■ FIGURE 7



```

'* Notes :The program generates a binary 3 digit sequence to
*:switch the multiplexer every 30 seconds. A second
*:port outputs a 3 digit sequence every 60 seconds to
*:keep track of which cylinder is being monitored.
*:A ground on GPIO.5 will stop the count as long as
*:the button is presssd.
*****

```

```

REM DEVICE = 16F627A
REM DISABLE LOW VOLTAGE PROGRAMMING
REM CONFIGURATION: INTOSC CLOCKOUT, WDT DISABLED, PWR UP ENABLED,
REM MCLR ENABLED, BROWNOUT DISABLED, NO PROTECTION

REM PORT B ARE OUTPUT, HOLD INPUT ON PORTB.3 (PIN 9)

REM RA5 (PIN4) IS MASTER CLEAR, RA6 (PIN15) IS CLOCK OUT TEST POINT.
CMCON = 7
TRISA = %00100000      'PORTA.5 IS MASTER CLEAR
TRISB = %00001000      'PORTB.3 IS HOLD INPUT
CNT VAR BYTE
DIGIT VAR BYTE

START:

FOR CNT =0 TO 7
IF CNT<2 THEN DIGIT =1
IF CNT = 2 OR CNT = 3 THEN DIGIT =2
IF CNT = 4 OR CNT = 5 THEN DIGIT =3
IF CNT = 6 OR CNT = 7 THEN DIGIT =4
PORTA = DIGIT
PORTB = CNT
IF PORTB.3 = 0 THEN GOSUB HOLD
PAUSE 30000          '30 SECONDS
NEXT CNT
GOTO START

HOLD:

```

```

IF PORTB.3 = 0 THEN GOTO HOLD
RETURN
END

```

the needed circuit.

— Arsenio C. Problete, Jr.

A A 40 watt fluorescent tube gives a lot more light than a 100 watt bulb because of its greater surface area; 10,000 mcd (10 candles, equivalent to 126 lumens) is an intensity measure and LEDs of that intensity usually have viewing angles of 20 to 30 degrees. You'll need 12 to cover 360 degrees and many more to cover a hemisphere. Without going through the math, I am going to estimate 31 LEDs in the hemisphere. If these are connected in series, the total voltage is: $31 * 3.5 = 108.5$ volts. The 250 VAC source will give 336 volts DC. The total power input at 20 mA is 6.7 watts which is not bad for 126 lumens of light. That is assuming you use an 11K, five watt resistor in series. Since you will only save a couple of watts by using PWM, I think the resistor is the best way to go.

My 100 watt incandescent lamp package lists the lumens as 1,700, so the LED light is 1/10 as bright. You can buy a commercial LED lamp to

■ FIGURE 8

MAILBAG

Dear Russell,

In your column in the September 2008 issue (pages 26 and 27), you gave an incorrect explanation of the operation of transformers (and by implication, inductors). Your explanation is a widespread misconception about Faraday's Law. Faraday's Law is based on the phenomenon that a time-varying magnetic field produces an electric field. The EMF induced in an inductor or the secondary winding of a transformer is due to this electric field, not the magnetic field. This is proved by examining the operation of a toroidal transformer. Because of the essentially total cancellation of the magnetic field external to the primary winding due to its geometry, if the secondary winding is wound on top of the primary winding, it is not even in the magnetic field of the primary winding. Yet, the

toroidal transformer works.

— Michael S. La Moreaux

Thanks for giving me the opportunity to correct any misconception. You are correct that the flux does not have to "cut" the turns of the secondary, as I may have said, but the induced voltage is due to the time varying magnetic field. If it makes sense to you that the electromagnetic field extends beyond the magnetic flux field and thereby induces the secondary voltage, I won't argue with you. But, it makes more sense to me to think in terms of flux coupling the two coils of a transformer. Faraday's Law says that an EMF cannot exist without a time varying magnetic field, so it really doesn't matter which you assume to be the driving force, as long as you are consistent. I know how (in principle) to calculate the induced voltage from a time varying magnetic field; I don't know how to calculate the induced voltage from an EMF without going through the magnetic flux.

replace a 100 watt bulb for about \$100, which is cheaper than building one yourself.

I use 40 watt fluorescent tubes in my house; two of them give 10X the illumination of a 100 watt bulb, so I think that is the best solution although perhaps not the most efficient.

A CYCLING CIRCUIT

Q I urgently need a circuit to cycle four pairs of thermocouple signals for a four cylinder air-cooled engine (CHT&EGT) at the cycle rate of 30 to 40 sec for the four cylinders. As each cylinder cycles on, I need it to also indicate the cylinder 1-2-3-4 on a seven segment LED. A selective hold switch would also be helpful for extended viewing of any particular cylinder. The power source is 12 VDC.

The circuit doesn't need any signal conversion. Also, there isn't any common ground. This circuit would replace having to manually switch from cylinder to cylinder.

— Art Schwedler

A I remember answering this question about a year ago, but can't find it in any issue. Anyway, I got feedback that I could have done it simpler, so I will try to do that this time.

There are eight thermocouples (four cylinder and four exhaust) which are to be read in sequence: cyl1, exh1, cyl2, exh2, etc. You evidently already have the thermocouple circuit and display; all you need is an automatic switching circuit.

In Figure 7, I am using a Fluke model 80TK thermocouple interface but if you are using an instrumentation amplifier and cold junction compensation, you can use that instead. The input impedance of the 80TK is high enough that the resistance of the analog switch will not cause significant errors. I don't know much about thermocouples, but I believe that the negative lead has to

have the same interface as the positive. That means eight connections on the PCB; same as the positive. The schematic shows CD4051, one of eight multiplexers because it is available in thruhole plastic DIP; but 74LV4051 is a better device, available in surface-mount TSSOP. The program for the PIC16F627A controller is Figure 8. As usual, I can send you a programmed PIC16F627A for \$5 if you don't have access to a compiler and programmer. NV



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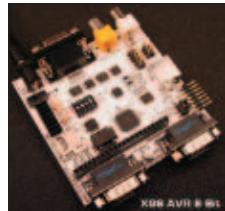
P R O D U C T S

- HARDWARE
- SOFTWARE
- GADGETS
- TOOLS

XGS AVR 8-BIT AND XGS PIC 16-BIT

The XGS AVR eight-bit is based on the Atmel Mega AVR644 processor and is a highly integrated development kit for exploring the Mega AVR processors in a fun and engaging way.

On the other hand, the XGS AVR eight-bit is designed to be a serious AVR development kit for schools, students, engineers, and anyone interested in learning AVR



programming. Clocked at over 28 MIPS, the XGS AVR eight-bit is a powerful development board. The system has the following features:

- AVR644 processor with 64K Flash/ 4K SRAM running at over 28 MIPS.
- 3.3/5V dual supplies.
- VGA.
- NTSC/PAL with color generation helper hardware.
- Micro SD card interface.
- Serial port.
- ISP and JTAG programming ports.
- PS/2 keyboard/mouse port.
- Expansion port header exporting numerous I/O, power, and signal lines for experimentation.
- 3.3/5V internally regulated supplies.

- Two game controller ports (Nintendo compatible).

The XGS AVR eight-bit kit provides a fun way to learn AVR programming in the context of graphics, audio, and simple game development. Instead of blinking LEDs and displaying digits on a seven-segment display, users will develop graphics applications that control the VGA and NTSC screen to learn AVR C and ASM. The kit is extremely competitive and comes with the following items in the bundle:

- 350+ page printed manual covering hardware, software, and numerous programming tutorials.

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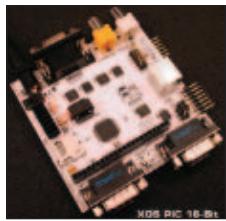
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- DVD-ROM with numerous examples and complete driver library including: graphics, sound, keyboard, SD card, serial comms, mechatronics, and more.
- Bonus materials on DVD-ROM include electronic copies of numerous game development and electronics gaming hardware books.
- XGS AVR eight-bit priced at \$139.99.

The XGS PIC 16-bit is based on Microchip's new 16-bit PIC24 processor and is a highly integrated development kit for exploring Microchip's 16-bit



microcontrollers, also in a fun and engaging way. The XGS PIC 16-bit is a serious PIC24 development kit for anyone interested in learning PIC programming. The system has the following features:

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- 3.3/5V internally regulated supplies.
- Two game controller ports (Nintendo compatible).

This kit is also extremely competitive and comes with the following items in the bundle:

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- PICkit2 programmer + USB cable.
- 9V power supply.
- A/V cable.
- Game controller.
- DB9 PC serial port to XGS header converter.
- DVD-ROM with numerous examples and complete driver library including: graphics, sound, keyboard, SD card, serial comms, mechatronics, and more.
- Bonus materials on DVD-ROM include electronic copies of numerous game development and electronics gaming hardware books.
- XGS PIC 16-bit priced at \$159.99.

**For more information, contact:
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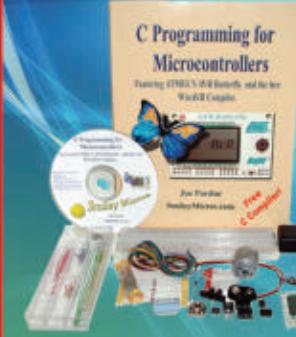
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GARAGE ACCESS GOES DIGITAL

An electric garage door opener is one of the greatest convenience devices ever created! Rain or snow, the weather doesn't matter. You hit a button from inside your car and the door instantly performs as commanded. By adding a digitally controlled keypad, one can make keyless entry easy for children, too.

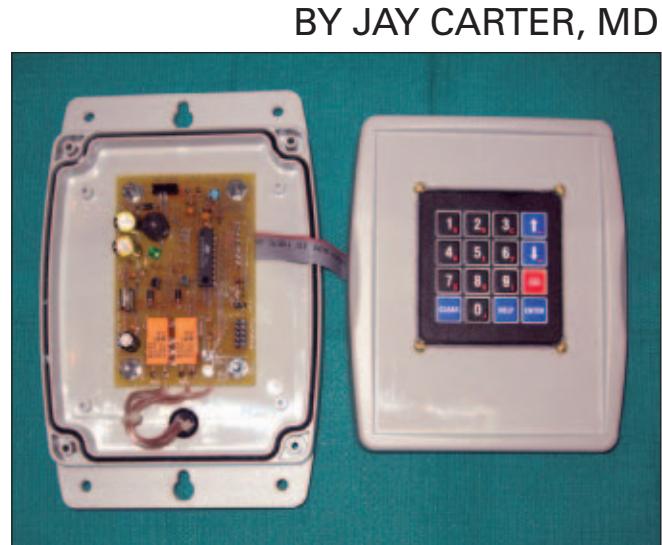
This project uses a single chip — an ATMEL AVR ATtiny2313 microcontroller — to read a keypad and trigger activation of up to two garage doors. The four digit access code can be programmed using the keypad itself, allowing one to easily change the code as desired. A built-in safety feature will stop the door with the single press of any key following door activation. Using only a handful of components, this becomes a truly useful weekend project. Photo 1 shows the project assembled and ready for installation.

Garage Door Interfacing

Most garage doors can be activated via two methods: a doorbell type pushbutton switch or wirelessly. This project mimics the doorbell switch, so it keeps costs down and eliminates the need to know your garage door's wireless frequency and encoding. On the back of most garage door units are two terminals which are wired to the pushbutton switch. The microcontroller activates a small relay when the correct access code is entered. The relay contacts are tied to the same terminals as the pushbutton switch. Enter the code and the microcontroller effectively pushes the button for you.

Reading a Matrix Keypad

The circuit for this project (shown in Figure 1) is centered around the microcontroller. The selected keypad has 16 keys, connected in a 4 x 4 matrix arrangement. Four wires connect to the four rows of keys, while four more wires connect to the four columns of keys. Pressing a key shorts the associated row and column wires together. For example, pressing the "6" key ties the



■ PHOTO 1. The garage access keypad project shown completed and ready for installation. One chip — the ATtiny2313 — runs the show. It scans the keypad, validates an access code, and drives two relays, activating the garage doors. The weatherproof enclosure includes a rubber gasket.

row 2 and column 3 wires together.

The microcontroller can scan the keyboard and tell if any key has been pressed. To do this, the four column lines are pulled high to +5 volts by resistors R4-R7. The microcontroller outputs a 1, or +5V on each of the four row lines. Then, one row at a time, the microcontroller outputs a 0 on the row line, pulling it low. The microcontroller then reads in the state of each of the four column lines. If one of the keys in that row is pushed, its column will be low. If there are no keys in that row pushed, all four column inputs will read high, being pulled high by the pull-up resistors. As an example, if the "9" keypad is pressed, the row 3 and column 4 lines are tied together. When the microcontroller pulls row 3 low, columns 1, 2, and 3 will read high, while column 4 is now connected to the low level and is read as low.

The microcontroller stores the sequentially pressed keys in a first-in, first-out (FIFO) buffer. The access code is four digits long, followed by the "Enter" key. If more than four keys are pressed, the oldest key press is overwritten, with the program always having the last four keys in the buffer. When "Enter" is pressed, the program checks the last four key presses against the access code. If a valid code was entered, the microcontroller activates a relay and closes its contacts, mimicking a doorbell pushbutton switch being pressed.

Holding the relay closed for about 3/4 of a second works well on my door openers, but the value can be

easily changed within the software.

Debouncing Switches

When one pushes a keypad or closes any switch for that matter, the switch contacts tend to bounce, making and breaking contact several times before assuming their new state. This 'contact bounce' is highly variable between switches, and even varies from activation to activation of the same switch. When viewed with an oscilloscope, one might see the switch open and close a half dozen times or more during its activation. The duration of the individual bounces is variable, and could be up to a millisecond or two, although shorter pulses are common. It may take up to 10 ms or even longer for the switch to assume a stable state. This bouncing occurs with both opening and closing mechanical contact switches.

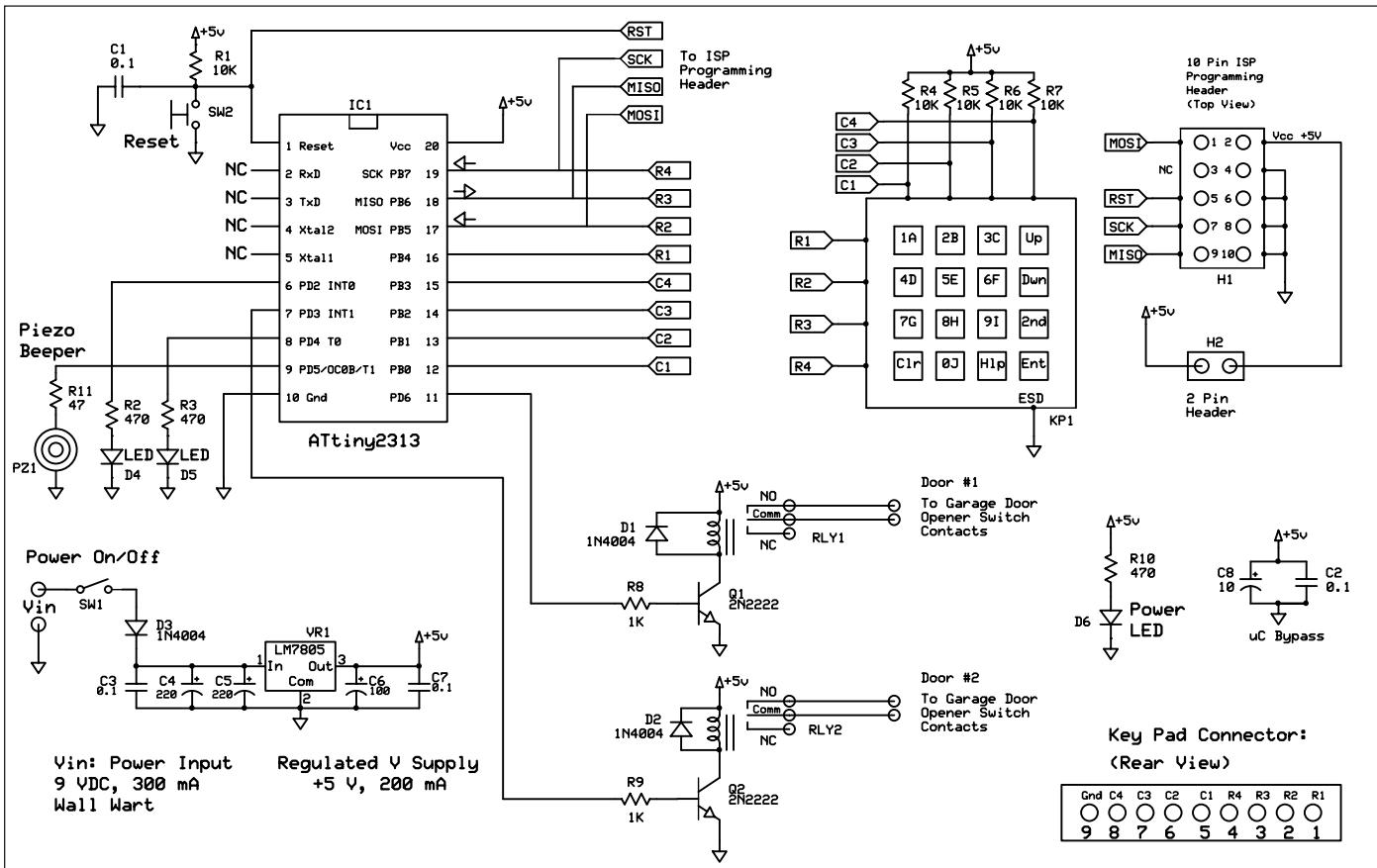
When one turns a ceiling light on or off, the bounce of the switch is imperceptible. When one is entering an access code, however, switch bounce is very important. If the circuitry and software do not account for switch bounce, the microcontroller might register one keypad press as multiple presses of the same key, making it impossible to correctly enter the code. Entering 1, 2, 3, 4 might be read by the microcontroller as if one had entered: 1, 1, 1, 2, 2, 2, 2, 3, 3, 4, 4, 4, 4, 4.

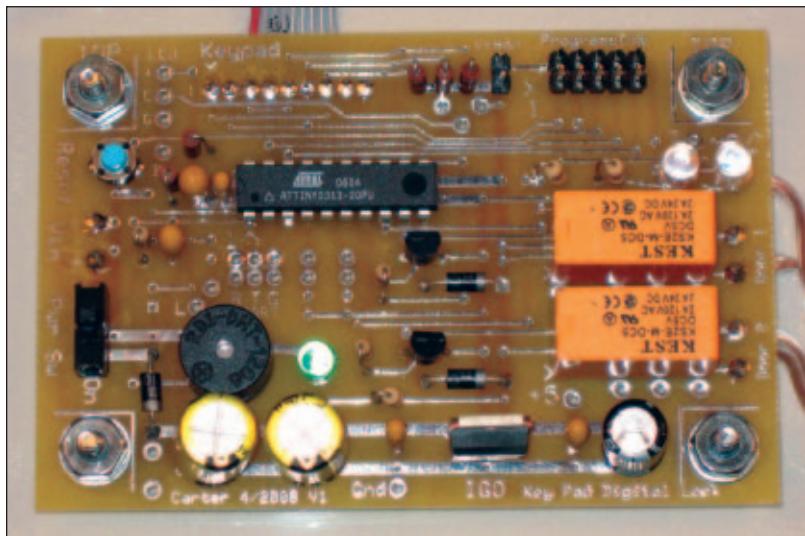
Although one can eliminate the bounce in hardware by placing a capacitor across the switch contacts, this

requires additional components and circuit board space. For high voltage circuits — where each bounce is associated with a small spark and the generation of electromagnetic interference — this approach may be needed. For this project, however, debouncing is done in software.

Many techniques exist for debouncing a switch in software. Perhaps the simplest technique — employed in this case — is a simple timer. Here, when a key is pressed its value is stored and the microcontroller just waits 75 ms before doing anything else. The switch may bounce numerous times, but these will be ignored by the microcontroller. After 75 ms, the microcontroller watches to see when the key is released. It again waits 75 ms to avoid detecting any switch bounce on the keypad release, and then resumes its main loop, watching for key presses. This may seem like a long time interval to wait to insure that one has skipped over any keypad switch bounces, but even taking 150 ms to read each key press would still allow the user to enter the access code at over six digits per second. This is much faster than the normal individual could possibly press the keys. A more efficient algorithm to detect key presses and eliminate the

FIGURE 1. The garage access keypad schematic. The keypad connects to port B on the microcontroller via a ribbon cable. The microcontroller interfaces with a matrix keypad, relays, LEDs, and a piezoelectric beeper. A generic five volt power supply rounds out the circuit.





■ PHOTO 2. A close up view of the ExpressPCB circuit board. The lower row of components comprise a regulated five-volt power supply. The two transistors seen below the microcontroller drive the two orange relays to their right. The programming header is located on the top right corner of the board.

switch bounce could be used if the microcontroller had other tasks to perform. In this case, no other tasks exist, and this simplistic approach works well.

Beep, Beep, Beep

Whenever a key is pressed, the microcontroller generates a short beep via a piezoelectric element. This provides feedback to the user, letting them know that the keypad press was detected. Piezoelectrics are powered with a square wave. This is easily generated by a microcontroller by toggling a digital output pin high and low, generating a string of pulses, ideally at their resonant frequency for clear tone generation. The volume of the tone generated diminishes as one moves off the resonant frequency. A 2 kHz tone played for 200 ms generates a nice feedback for the user. The frequency and duration can be easily changed in software to best match one's specific element and preferences.

The piezoelectric element specified in the parts list draws about 90 mA when powered with a 5V square wave. The ATtiny2313 can source up to 40 mA per pin for driving external devices, (200 mA chip total). The series resistor – R11, 47 ohms – limits the current drawn to 10 mA. One could substitute a 22 ohm resistor, doubling the current, and increasing the volume, if desired.

Relay Driver

The relays selected for this project draw about 40 mA at 5V. This is right at the maximum current allowed per pin on the microcontroller. The microcontroller could power the relay directly, but for long term, reliable operation it is best to avoid operating the chip right at its maximum limits. Designing in a safety margin also protects the chip in case a particular relay actually draws more current than expected.

A 2N2222 transistor is used to drive each relay. A high on the microcontroller pin turns on the transistor

via its base resistor. The microcontroller pin now sources less than 5 mA when driving the transistor – well within the 40 mA limit. The transistor is operated in saturation mode as a switch, being either fully turned on or off. When on, the collector current activates the relay. This general-purpose NPN transistor can handle 600 mA of collector current. It is coasting along at 40 mA, and does not require a heat sink to keep it cool.

Each of the two relays have a reverse-biased diode across their coils (D1 and D2). This is a crucial item when driving an inductive load such as a relay coil. When the relay is turned off, the energy stored in the coil can generate a brief, high voltage spike across its terminals. This spike can easily damage the driver transistor. The diode clamps this spike, protecting the driver circuitry.

Flashing LEDs

The ATtiny2313 has far more digital input/output pins than are needed for this project. Two spare pins were used to drive two LEDs. The current software turns LED #1 or #2 on whenever Relay #1 or #2 are activated. They can be mounted on the project's front panel for additional user feedback, left on the circuit board, or they can be completely eliminated from the circuit. Being under software control, their actual usage is at the discretion of the programmer. The LEDs have a series resistor to limit their current to about 10 mA. This is within the limits of both the LEDs and the microcontroller pin source current maximum of 40 mA.

Microcontroller Clock

All microcontrollers require a 'clock' to run. This clock is actually a square wave which drives the internal CPU and causes the microcontroller to execute sequential instructions in its program. This particular microcontroller can run on either an internal oscillator and external crystal, or an external square wave clock signal. As there was no need for any precise timing for this project, the internal oscillator was selected. The microcontroller is set to use its internal 8 MHz clock source when it is programmed. If one were to modify the project to automatically upload the date, time, door, and access code to a computer logging program, using the microcontroller's serial port one would want to utilize an external crystal for precise timing and reliable serial communications.

Power Supply

The power supply voltage for the ATtiny2313 can range from 2.7 to 5.5 VDC. Five volts was selected for convenience, as 5V relays were used to interface to the garage door controllers. The circuit draws less than 20 mA in its usual state, awaiting someone to enter a keypad code. With all of the peripheral devices (two relays, two software controlled LEDs, the power supply's LED, and the piezoelectric beeper) turned on, the circuit could potentially draw a maximum of about 130 mA. In actual practice, the maximum current drawn by the circuit is less than one half of this value, about 65 mA when one relay is active. The LM7805 is a three-terminal positive voltage regulator which can supply up to 1A of current at 5V. At these low current levels, the regulator runs cool without an attached heatsink.

A 9 VDC, 350 mA wall-wart type power supply is used to power the circuit. The 9V feeds the voltage regulator which powers the remainder of the circuit. Older wall-warts were typically unregulated. Their usage required a voltage regulator to provide a fixed voltage to the microcontroller, and to prevent exposing the microcontroller to an over-voltage. Newer wall-wart power supplies are available which incorporate internal voltage regulators. Using one of that type would eliminate the need for the LM7805.

Outdoor Exposure

By its very nature, this project is mounted outdoors. This allows one to enter an access code and thereby raise the garage door for easy entry. The keypad and enclosure were both selected due to their indoor/outdoor weather rating. The plastic enclosure's top and bottom halves incorporate a rubber gasket to maintain a watertight seal. Additionally, a bead of silicone was placed around the keypad to keep the enclosure watertight. This design utilizes a plastic keypad, plastic enclosure, and exposed mounting screws. A higher level of security and vandalism protection could be provided by using an all metal keypad, metal enclosure, and inaccessible mounting hardware.

This wasn't necessary in my neighborhood.

Software and Features

The heart of any microcontroller project is its software program. AVR microcontrollers are most commonly

PARTS LIST

ITEM	QTY	DESCRIPTION
□ IC1	1	ATtiny2313 (SparkFun)
□ KP1	1	Keypad, 4x4, matrix format (All Elect: Cat# KP-23)
□ VR1	1	LM7805 three terminal linear voltage regulator
□ D4-D6	3	LEDs
□ PZ1	1	Piezo beeper, 5V (All Elect: Cat# PE-52)
□ Q1,Q2	2	2N2222 NPN transistor
□ RLY1, RLY2	2	Relay, 5V coil, DPDT, 16 pin DIP profile (All Elect: Cat# RLY-625)
□ D1-D3	3	1N4004 diode
□ SW1	1	On/off switch, PCB mounted
□ SW2	1	Reset switch, normally open, PCB mounted
□ H1	1	10 pin programming header, PCB mounted
□ H2	1	2 pin header, PCB mounted
□ R1, R4-R7	5	10K
□ R2, R3, R10	3	47Ω
□ R8, R9	2	1K
□ R11	1	47Ω
□ C4, C5	2	220 µF 16V
□ C6	1	100 µF 16V
□ C8	1	10 µF 10V
□ C1-C3, C7	4	0.1 µF 16V

Miscellaneous:

9V 300 mA wall wart power supply; printed circuit board; waterproof enclosure (PacTec OD56 Kit; gray); header shorting connector; grommet for wires to exit enclosure; board, keypad and enclosure mounting hardware; silicon sealant; twin lead wire to wall wart and garage door opener to switch contacts

Websites for further information

Atmel	www.atmel.com
AVR Freaks Forum	www.avrfreaks.net
Bascom-AVR	www.mcselec.com
ButtLoad	www.fourwalledcubicle.com
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PacTec Enclosures	www.pactecenclosures.com
PonyProg	www.lancos.com
Spark Fun Electronics	www.sparkfun.com
Jay Carter	www.docjc.us

Footnotes

The PonyProg Serial Device Programmer is available from Claudio Lanconelli. The program and further information is available at www.lancos.com

ButtLoad (Butterfly software Loader) is available from Dean Camera. The program and further information are available at www.fourwalledcubicle.com

Parts Suppliers

All Electronics	www.allelectronics.com
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programmed in assembly language, C, or Basic. This project was programmed using Bascom-AVR Basic. Roughly 2/3's of the available memory is used by the program, allowing room for future revisions or enhancements.

The current software includes several convenience features. By first entering a "Programming Code," the microcontroller beeps three times and the user then enters the access code of their choice. This code is saved in the microcontroller's EEPROM memory for future use. The access code can be changed at any time by simply re-programming it.

Many programs contain a "back door" or secret access code, and this project is no exception. A secret access code also exists which will always work and can not be changed by user re-programming described above.

If the user presses the second key on the keypad prior to entering their access code, the second door (Door #2) is activated instead of Door #1. A single keypad and access code can therefore be used to open or close either door.

Safety First

Once a valid access code is entered and a door is activated to either open or close, one can press any key on the keypad to instantly stop the door. This feature is

active for 30 seconds after entering a valid access code. If the incorrect door was activated or if one needed to stop the door quickly, it can be easily done without remembering and re-entering the entire access code.

Programming the Microcontroller

The operating program – written in Basic – must be compiled to generate a hex file which can be loaded into the ATtiny2313 microcontroller. Both versions of the program are available on the *Nuts & Volts* website (www.nutsvolts.com). If you are familiar with programming AVRs, you are all set. A programmer is used to load the hex file into the microcontroller and many different programmers exist. A low cost approach is the AVR STK Serial Port Dongle Programmer available from SparkFun Electronics (~\$12.95). This device is used with the free PonyProg software. An ATMEL Butterfly demonstration board (~\$21.00) can be easily converted into an AVR ISP programmer using the free ButtLoad program. The ATMEL STK500 (~\$85.00) development board/programmer provides extensive testbed and programming capabilities.

Additional options and further information on programming can be found on the ATMEL and AVR Freaks websites given in the parts list. Instructions on downloading the program (hex file) into the microcontroller chip are provided with each of the above programmers, and in tutorials on the ATMEL, AVR Freaks, and SparkFun Electronics websites.

A circuit board was developed for this project using ExpressPCB and their software. The board layout is available and is posted with the software. The board includes a 10 pin programming header for use with the above programmers. Additional pads are provided on the board for adding an external crystal, its capacitors, an LCD contrast potentiometer, and for connecting to the USART pins. These are unused in this project, but are useful for experimentation.

Let Me In!

This project demonstrates the incredible power and capability of small, inexpensive microcontrollers to perform everyday tasks and make our lives easier. With just a handful of components, a truly useful and convenient project can be assembled in a weekend. It demonstrates interfacing to a low cost matrix keypad and the software techniques required to read and debounce the keypad input. Additionally, the project demonstrates interfacing a microcontroller to LEDs, relays, and piezoelectric beepers.

Keypad access is both a great convenience and security measure. This project shows the ease of its implementation. But stay tuned for Garage Access Version 2, using ATMEL's biometric fingerprint Fingerchip sensor to make keypads a relic from the past! **NV**

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HIGH RESOLUTION TIME-LAPSE MOVIES USING A STILL CAMERA

By Balakumar
Balasubramaniam

Making time-lapse movies is child's play these days as many camcorders come factory equipped with features that allow you to take pictures periodically once every few seconds. The pictures can then be assembled using a freeware like Windows Movie Maker. But, there is one major limitation to taking this approach for time-lapse movie making: the poor resolution of most inexpensive camcorders. What if you wanted to take a time-lapse movie with a 6 megapixel resolution per frame? Alternately, have you ever been the designated photographer of the party and wished your camera could automatically click away the celebrations from a vantage point while you enjoy the party?

Enter CamTim! CamTim is a digital camera hack that will convert your digital camera into a high-res time-lapse camera. The hack works the simplest if the camera has a single button trigger. You can select the inter-frame interval from a few seconds to a few hours with hardware switches and your camera will click away for eternity. And best of all, building the entire circuit on a RadioShack breadboard will cost less than \$30!

The Hack

There are two main components to complete before we get all this to work. First, we'll hack the camera trigger to allow external triggers. Then, we'll build the external trigger circuit. Let's get started with the trickiest one first!

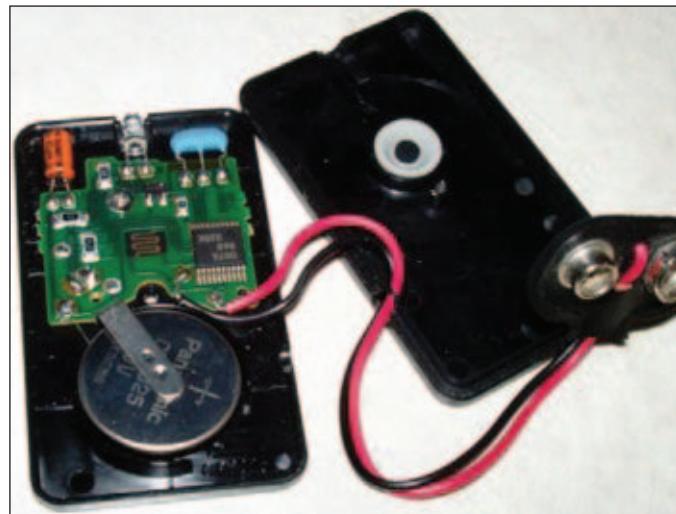
The Camera Trigger

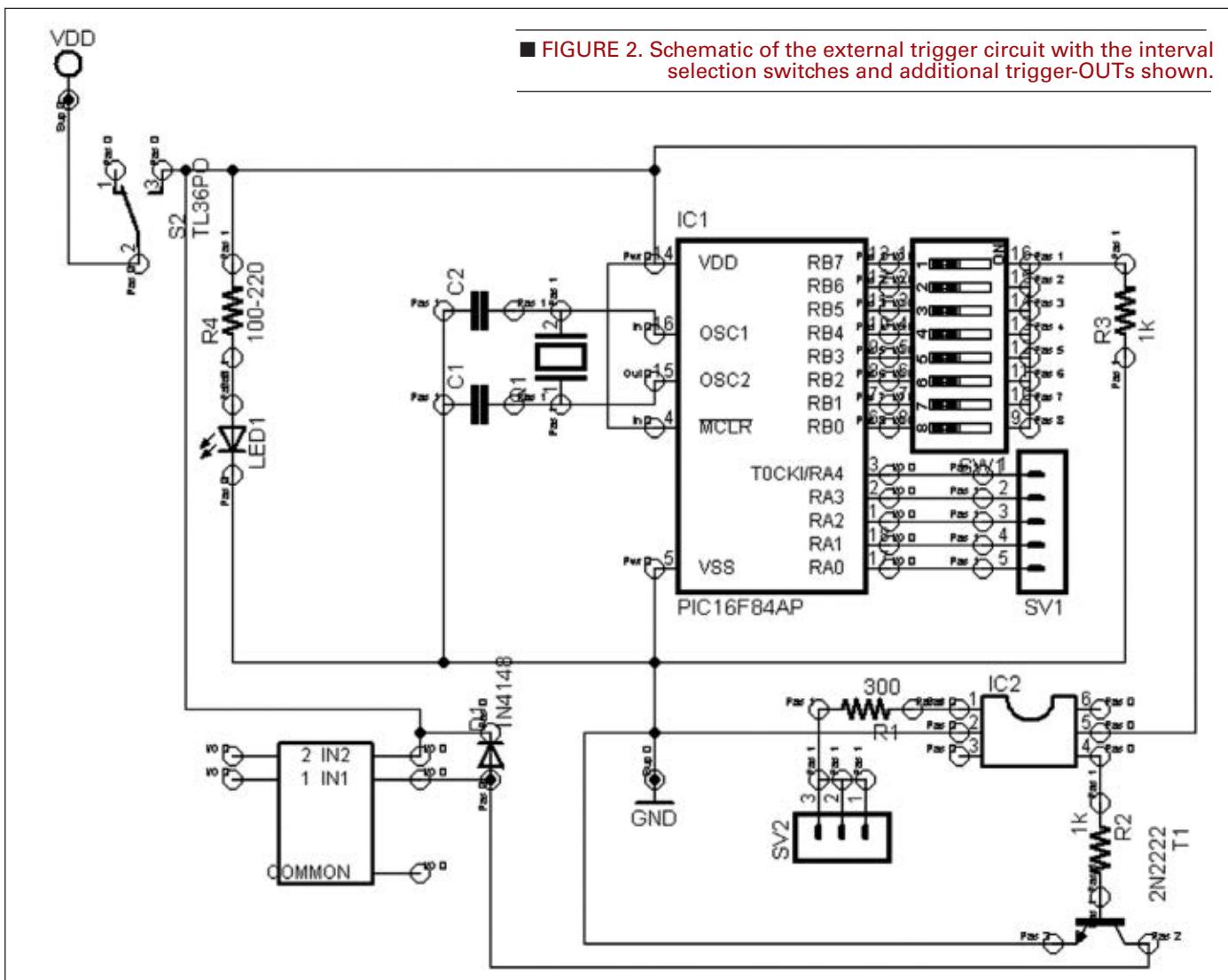
All cameras work the same way: Press a button and the camera will snap a picture. Our hack works by handing over the button-press part to a microcontroller. The first step is to figure out where the buttons of the remote or the camera terminate on the respective (printed circuit boards). In Figure 1, we show the remote controller of an Olympus C5000-Zoom camera and the location of the button terminals. Solder a 9V battery connector to the terminals, bring the terminals out of the remote control's body as shown, and seal the remote once again.

The Trigger Circuit

Next, when the button terminals are electrically closed, the camera will take a picture. (It goes without saying that if you are hacking a remote control, the IR LEDs should point towards the camera!) In this project, we use a mini-relay to electrically close the terminals from step 1 (Figure 2). The relay is driven by one of the pins

■ FIGURE 1. Wiring the remote for external trigger.





PARTS LIST

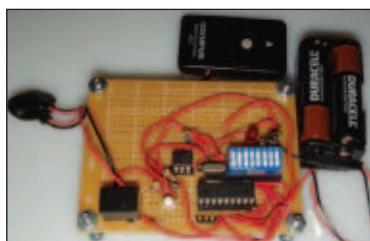
ITEM	SOURCE	PART#	QTY
❑ Relay	RadioShack	QUAZ-SS-105D	1
❑ Switching Diode	RadioShack	1N4148	1
❑ Optocoupler	Digi-Key	MCT2E	1
❑ Microcontroller	Digi-Key	PIC16F84A/04P	1
❑ Transistor	Digi-Key	2N2222	1
❑ Crystal 4.0 MHz	Digi-Key	CTX006-ND	1
❑ Capacitors (22 pf, C1 & C2)	Digi-Key	P4841-ND	2
❑ Resistor (1K)	Digi-Key	1.0KQBK-ND	2
❑ Resistor (220)	Digi-Key	220QBK-ND	1
❑ LED	Digi-Key	516-1401-ND	1
❑ Switch	Digi-Key	EG2355-ND	1
❑ DIP-8 Switch	Digi-Key	450-1408-ND	1
❑ Male Breakaway Header	Digi-Key	A34259-40-ND	1
❑ 9V Battery Strap	Digi-Key	237K-ND	2

from a PIC16F84AP microcontroller's PORTA. Since the relay typically requires more current than the microcontroller can supply, we drive the relay using a single stage current amplifier built with a 2N2222 BJT operated in the common emitter configuration. Relays are notorious for the back EMFs they generate, and without the protection offered by the 1N4148 switching diode biased suitably, the amplifier stage is in danger of a burn-out.

Clearly, we require only one pin from PORTA to drive the relay. In our case, we leave the other pins for future expansion and code the PIC such that the output pulse frequency in pin 5 is twice that of pin 4, which is twice that of pin 3, and so on. We provide one more protection for the microcontroller using an optocoupler (MCT2E) between PORTA and the amplifier stage.

The inter-frame interval setting for the time-lapse is selected using eight mini-switches connected to PORTB of the PIC. When the circuit is powered on, the PIC reads the switch settings (encoded in binary to read seconds) and selects the delay. Using a counter in the code, the PIC

FIGURE 3.The CamTim trigger circuit along with the C5000-Zoom remote and battery pack



sends out a trigger signal every few seconds. Of course, this is a very basic circuit and code.

You could also program the PIC to perform other complicated functions including using an external trigger to start the time-lapse using the unused pins from PORTA. Yet another possibility would be to use the interrupt signal when the status of PORTB changes to modify the inter-frame interval. This would prevent the necessity of restarting the circuit after every interval selection.

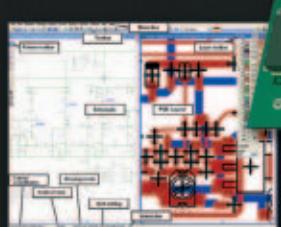
I built the entire circuit on a RadioShack PCB using the parts given in Table 1, and placed it securely inside a metal container. It is also best to mount the PIC on female headers to simplify the task of reprogramming. You can see some of the time-lapse movies I have taken using CamTim at: <http://ziggid.com/CamTim/tlapse>. The PCB layout is available from: <http://ziggid.com/CamTim/pcb>. NV

The source code is available at <http://ziggid.com/Software> and on our website www.nutsvolts.com.

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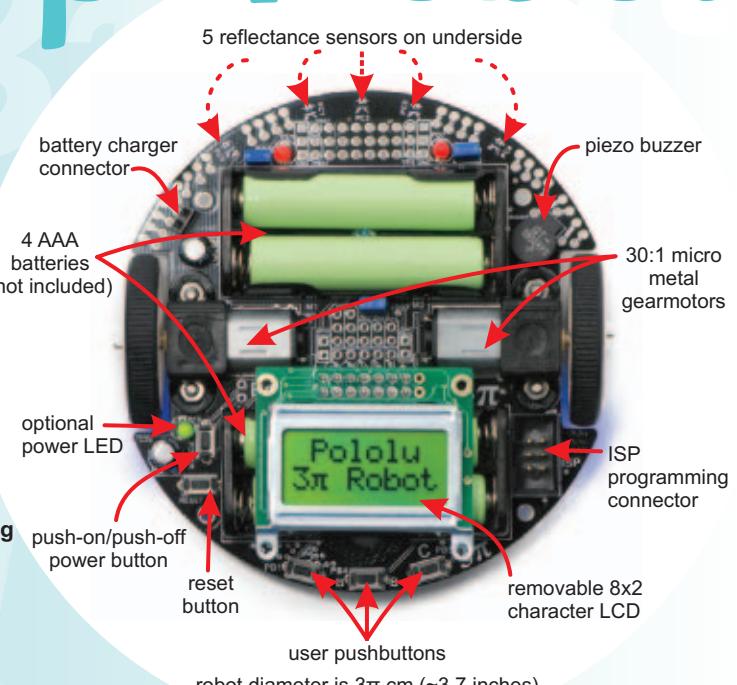
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Makin' MIDI: mistralIXG

A USB connected, PIC-based

MIDI Synthesizer

BY STEVE RUSSELL

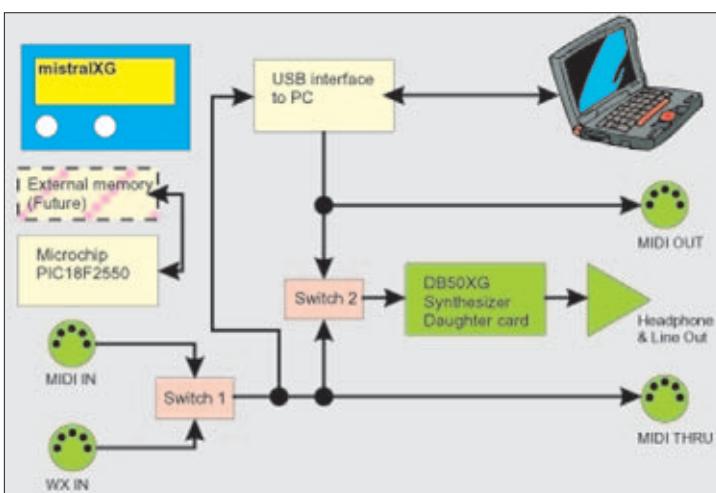
PART 1

mistralXG is a MIDI synthesizer based on a MIDI daughter card such as the Yamaha DB50XG. It could also be used as a USB MIDI switching and monitoring device without the daughter card. In this first of two articles, I'll explain how **mistralXG** operates and discuss the main technologies it uses. The second article will look at the hardware and software in more detail. Parts cost for the project is \$20 to \$30, excluding the daughter card, power supply, and enclosure.

Choosing a Project

A couple of my earlier projects were based on the PIC12C508A – one of the least powerful Microchip PIC microcontrollers (MCUs). Developing with them was great fun and provided my first experience with these fantastic little devices. But for my next project, I wanted to use a

Figure 1. mistralXG block diagram.



more powerful MCU and utilize some of the wide range of on-chip peripherals.

I've dabbled in MIDI for many years and, as my current PC's sound card doesn't have the necessary WaveBlaster-compatible connector, had an unused Yamaha DB50XG synthesizer daughter card. The Internet revealed some designs that use the DB50XG as a stand-alone synthesizer, but that just fed MIDI data to the card. I

wanted something a little more capable to allow me to play my MIDI wind controller away from my computer. This was an ideal goal for my project.

In August 2005, *Nuts & Volts* had published Robert Lang's MIDI-nator design, which showed that a hobbyist could create a USB-based MIDI device. But, rather than use MIDI-nator as a starting point, I wanted to create a completely new MIDI implementation so that I knew exactly what the device was and was not capable of.

Start at the Beginning

Late in 2007, I began thinking about the design. I burned the MIDI-nator project code into a PIC18F2550 to see it in action and, while it worked well, it was evident that there was a steep learning curve to designing with USB. Thankfully, there is plenty of information avail-

able (see Resources). Microchip also provides comprehensive datasheets – the PIC18F2550 document runs to 430 pages – so I had a lot of reading to do. A few months later (after sketching out some different approaches), I started serious work on the design.

Referring to **Figure 1**, the PIC18F2550 is the heart of mistralXG. It manages data flowing between the MIDI ports and the PC via its serial and USB ports, and provides logic and control for the MIDI switches and the user interface (two pushbuttons and an LCD display).

The code offers the following features:

- Selecting which MIDI stream is sent to the synthesizer
- Running Status control for MIDI OUT
- MIDI data filtering
- MIDI OUT and MIDI THRU control
- Adjustment of LCD brightness
- Monitoring of MIDI IN and MIDI OUT activity
- Maintaining and displaying error information

Technology Overview

Let's take a brief look at some of the technologies that are used in the design. If you really want to know how mistralXG works, there's no substitute for diving in and reading up on this stuff. There are also copious comments in the source code, which is available on the *Nuts & Volts* website at www.nutsvolts.com.

MIDI: The Musical Instrument Digital Interface

MIDI is a serial protocol for passing messages between controllers and music synthesizers. Commands such as "Note on," "Bend pitch," "Note off," and "Change instrument" control the sounds a synthesizer makes. Sixteen channels (1-16) – each mapped to a single instrument – are defined for a single MIDI connection, but MIDI does not define which instrument each channel represents. MIDI composers have to decide the instrument-to-channel mapping for each tune.

A command might say, "Play Middle C on channel 5, medium loud." Three bytes are required to construct this command. These are (in hexadecimal) 0x94, 0x3C, and 0x40. The first four bits of 0x94 (the "9") indicate this command is "Note on." The "4" in 0x94 says that the note should be played on channel 5 (counting starts at 0 for channel 1). Byte 2 selects note number 60 (0x3C) which is middle C. Notes 0-127 are defined (from low to high pitch). The last byte gives the volume, with 0 being silent and 127 (0x7F) being loudest.

Instruments are numbered 1-128 (0-127) and mappings are again arbitrary. The General MIDI specification, however, defines a mapping most synthesizers can be set to match. When playing a MIDI file, you have to make sure that your synth uses the correct mapping to prevent notes meant for one instrument being played by another – perhaps even the drum kit! One synthesizer's piano

may sound different from another's, but at least they both generate the right type of sound for the music.

MIDI hardware recognizes command bytes because their most significant bit (MSB) is set to 1. Command bytes are followed by 0, 1, or 2 data bytes which have their MSB=0. Details of the commands and how to interpret them can be found in the Resource links.

MIDI is real-time

MIDI data are transmitted in real time. As soon as a synthesizer receives a completed "Note on" message for a particular note and channel, it starts to play the note. It will continue to sound until a "Stop note" command for the same note and channel is received. So, a synthesizer connected to a MIDI keyboard will reproduce the exact timing of the notes as they are played by the musician, with a slight – usually indiscernible – delay to allow for constructing, transmitting, and receiving the MIDI messages. If multiple MIDI devices are chained together, this delay can become significant and must be kept in mind when setting up complex MIDI systems.

MIDI was launched about 25 years ago, and the specification has changed little since then. The data or bit rate of 31.25 kHz seems very slow by today's standards, but MIDI's wide adoption within the electronic music industry has ensured its survival, and it is likely to be around for many years to come.

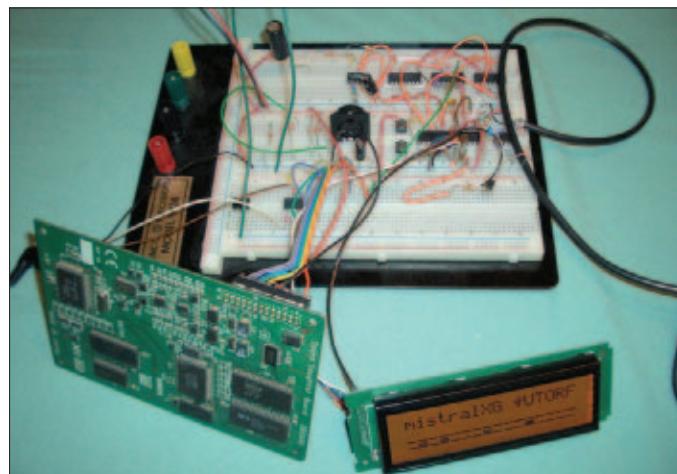
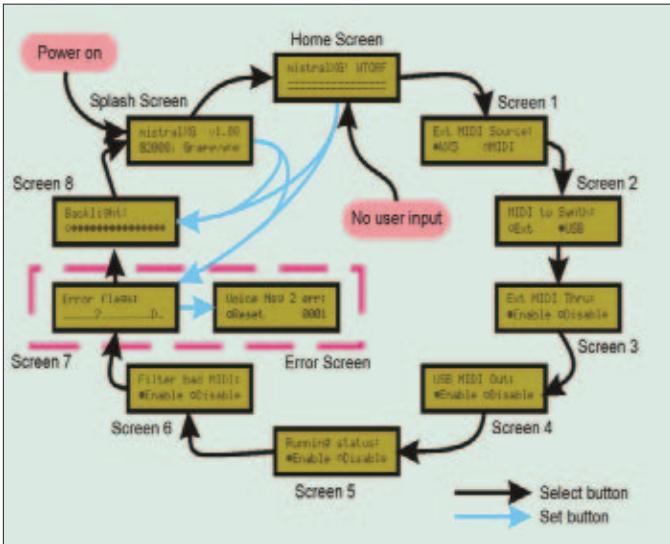


Figure 2. mistralXG prototype.



Figure 3. mistralXG Home screen.

Figure 4. Accessing user options screens.



USB: the Universal Serial Bus

PCs used to have a variety of “legacy” ports (serial, parallel, etc.), carried over from the first PC shipped in the early 1980s. Setting these up to attach peripherals such as printers was often a configuration nightmare. Now, USB has made connecting even very sophisticated devices to your PC almost trivial.

The end-user’s gain has been at a cost to the developer. Designing serial or parallel port hardware is straightforward, but getting a peripheral to communicate using USB is not for the faint-hearted. It requires a complex combination of hardware and software. Fortunately, Microchip has made it easier by providing a few microcontrollers with USB hardware. They also provide a software framework that does most of the housekeeping needed to make USB work. This allows the designer to focus on just the application-specific USB code. In practice, however, the designer needs a good understanding of USB to be able to debug problems as they arise during development.

Tell me what you are

When you first connect a USB device to a computer, it goes through a process called enumeration. This tells the computer what the device is and what drivers are required, among other things. When enumeration completes successfully, the device becomes available to the system. Suitable USB MIDI drivers are provided with both Windows and Linux.

USB data are collected into packets and transmitted in 1ms “frames” (high-speed USB 2.0 uses shorter “microframes”). Thus, there is a mismatch with the real time needs of MIDI. As a result, some MIDI purists won’t use a USB MIDI implementation but, in practice, this does not usually cause a problem, especially for simple MIDI configurations.

Liquid Crystal Display (LCD)

Several LCD types are available. Many – including the one used here – are based on the Hitachi HD44780 controller. This chip supports a number of different display configurations, from eight characters in one row, up to four rows of 20 characters. mistralXG uses a 16x2 display. Four or eight data lines (number selected in software) and three command lines give you complete control of the display. Using only four lines (four bit mode) for data makes it an attractive proposition for microcontroller based designs, where pin counts can be at a premium. A few simple routines provide all the functions needed to write messages to the display. They take care of all the critical timing requirements so that the rest of the code doesn’t have to worry about them.

The PIC18F2550 Microcontroller

Microchip offers an impressive range of microcontrollers that incorporate a wide variety of on-chip peripherals. These include serial ports, A/D converters, timers, EEPROM memory, and more. One less common peripheral is the 2550’s USB port. It is USB 2.0 compatible, supporting both the full speed (12 Mbps) and low speed (1.5 Mbps) modes, but not the high speed (480 Mbps) mode. MIDI’s 31.25 kbps data rate means that the full speed mode is sufficiently fast for mistralXG.

Software is needed to drive the USB hardware so that your PC can enumerate and recognize a valid USB device. Fortunately, Microchip’s USB Firmware Framework does a lot of the work for you, leaving you to concentrate on your application code.

The mistralXG code is around 5-6 KB, much smaller than the 16 KB available in the 2550. I chose this device rather than its smaller sibling (the PIC18F2455) as I wasn’t sure how large the code would grow. It also means there’s plenty of room to add additional features at a later date, such as the external storage shown in **Figure 1**.

Putting It All Together

Okay, so that’s a whistle-stop tour of the main technologies used in mistralXG. Now let’s look at how the user interacts with the unit, leaving the technical detail to the next article. As a taster, though, you can see the prototype in **Figure 2**.

At front left, you can see the DB50XG, with the LCD to the right. The PIC18F2550 is the large chip to center-right of the breadboard.

The user’s view of mistralXG is four MIDI ports (MIDI IN, WX IN, MIDI OUT, and MIDI THRU), a USB port, the LCD display, and two pushbuttons (*SELECT* and *SET*). When power is applied, a Splash Screen shows the firmware revision and copyright notice (you may use the code for personal projects, but not commercially). After a few seconds, the display changes to the Home Screen

shown in **Figure 3**.

The Home Screen displays are:

USB Status: The “cactus” – six characters from the end of the first row is my low-res attempt at the USB symbol. It is displayed when mistralXG is connected to your PC. The next five symbols show the status of the user options (discussed later).

Error Status: The space to the left of the USB symbol shows the global error flag and is normally blank. If an error occurs, this changes to an “!” and the error screens become available.

Real-time MIDI Activity Monitor: The second row shows MIDI IN (top line) and MIDI OUT (bottom line) activity. **Figure 2** shows the data being transmitted from the PC on channels 1, 3, 5, 6, 7, and 10 (left to right). No data is being transmitted to the PC (all channels are low on the top line). The MIDI IN monitor remains active even when mistralXG is not connected to your PC.

The remaining screens allow you to access user options and are displayed by pressing the *SELECT* button. The *SET* button changes settings or performs some other useful action. From the Home and Splash screens, *SET* provides quick access to useful features (see **Figure 4**). No matter which screen is being displayed, after a few seconds without a button being pressed, the display returns to the Home Screen.

Using mistralXG

SELECT cycles through the various screens, as shown in **Figure 4**. Pressing *SET* toggles or otherwise modifies the setting for each particular screen. I’ve already discussed the Home Screen, so now let’s take a look at the others.

User Options

The first two screens allow you to select which MIDI stream is transmitted to the synthesizer. The first option flag on the Home Screen (“U” in **Figure 3**) shows which stream has been selected. Screen 1 lets you choose between the MIDI IN and WX IN inputs (Switch 1 in **Figure 1**), while Screen 2 selects between the output of Switch 1 and USB data from the PC (Switch 2 in **Figure 1**). The display shows “M,” “W,” or “U,” depending on your choices. If USB is selected and mistralXG is not plugged into your computer, Switch 2 automatically selects your M/W choice, reverting to U when the USB connection is reactivated.

Screens 3 and 4 control the MIDI THRU and MIDI OUT streams respectively. When enabled, MIDI THRU receives the M or W stream coming from Switch 1. MIDI OUT echoes the MIDI stream coming from the PC. Selecting Disable in these screens switches their respective streams off.

Screen 5 controls MIDI Running Status. This feature of MIDI reduces the amount of data transmitted. It works on the principle that if a status byte would be repeated, it can be omitted. So, if consecutive MIDI commands are all “Note on, channel 5” (0x94 as already seen), then the command byte is omitted for subsequent notes until a new status byte is required. This reduces the amount of data transmitted by 10% to 15%. Normally, Running Status should be enabled, but you could disable it if you think it may be causing problems for a receiving device.

Certain byte sequences are invalid MIDI commands. A receiving device should ignore these, so filtering shouldn’t be necessary. If you think invalid messages may be causing problems, however, the filter can be enabled in Screen 6. Invalid sequences are reported as errors by mistralXG, whether or not the filter is active.

Screen 7 is not normally displayed. It shows the error types that have occurred, and only becomes available when an error has been registered. In this case, the Home Screen global error flag is displayed (see **Figure 4**). Pressing *SET* while on Screen 7 shows the individual error screens. A second press of *SET* resets the specific counter.

After zeroing a counter, pressing *SET* once more allows you to clear all error counters and return to the Home Screen. If you’d rather examine the individual error

RESOURCES

Here are a few links that I have found useful. Links come and go, of course. If that happens, just load a few key words into your favorite search engine and you’ll find lots out there.

MIDI

MIDI specifications: www.midi.org (unfortunately, these have to be purchased, but web sources are almost as good). There are hundreds of MIDI-related sites on the Internet. These are just a couple of the top hits from Google: <http://ccrma-www.stanford.edu/~craig/articles/linuxmidi/misc/essenmidi.html> www.computermusicresource.com/MIDI.Commands.html

USB

USB Specifications: www.usb.org. Here you can find both the USB 2.0 spec (650 odd pages!) and more specific documents, including the USB-MIDI spec.
USB in a Nutshell: www.beyondlogic.org/usbnutshell/usb1.htm

LCD

There are many websites describing these popular displays. Here are just a couple:
www.doc.ic.ac.uk/~ih/doc/lcd/
<http://mil.ufl.edu/imdl/handouts/lcd-faq.htm>

PIC18F2550

PIC MCU Information: www.microchip.com
PIC Discussion Group: www.piclist.com

counts, *SELECT* cycles through those error screens that have non-zero counters. When all counters have been reset, the global error flag is cleared. Individual error screens are exited by allowing the display timeout to return you to the Home Screen or by choosing to reset all counters.

The LCD backlight brightness is controlled in Screen 8. Nine levels – from Off to Maximum – are available.

Finally, we return to the Splash Screen and then the Home Screen. **Figure 4** also shows shortcuts to the backlight and error screens using the *SET* key from the Home Screen.

All option settings (including backlight level) are saved in non-volatile memory and reloaded when *mistralXG* is switched on.

Error Flags and Counters

mistralXG tracks a number of different errors that may occur. The second line of Screen 8 (the error flags) shows the status of the 16 error types. An underscore ("_") in a position indicates that the related error has not occurred. Each position has its own error character. If every error type had occurred, the flags would look like this:

BFOD12012SE459DM

Here's a quick summary of the error types. More detailed information is in the source code:

- BFO These flags indicate errors receiving MIDI data from the inputs (receive buffer overflow, EUSART framing error, EUSART overflow error).
- D Unexpected data byte (MIDI command byte expected).
- 12 Unexpected channel command byte (commands

expecting one and two data bytes, respectively).
012 Unexpected System Control command byte (commands expecting zero, one, and two data byte, respectively).

- S Unexpected Sysex command byte.
- E Unexpected End of Sysex command byte.
- 459D Invalid command byte (0xF4, 0xF5, 0xF9, 0xFD).
- M USB-MIDI input buffer overflow.

Errors are rare, but you can induce them by switching the input stream between "M" and "W" while a track is playing.

Next Time: Technical Details

Okay, that about wraps things up for this month. I hope you can see that *mistralXG* offers a lot of flexibility, and that you are interested enough to want to try either building it for yourself or using it as a base for your own project.

Next time, I'll take you through the details of the hardware and software that bring *mistralXG* to life. **NV**

About the author

Steve Russell started out his working life as a hardware design engineer. Somewhere along the way, he discovered computers and began designing subsystems of various types for them, working for a multi-national computer company before moving into software development. Currently developing code in Java and Python, he still misses the baleful green glow of an oscilloscope in a darkened lab, late at night ...

You can contact Steve at pic.projects@grapevyne.com

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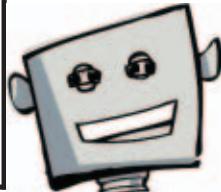
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Wire-wrap and low cost TTL parts have made the puzzle-solving fun of digital logic design accessible to hobbyists and engineers everywhere. Although TTL works fine for small designs, it becomes expensive and time consuming for larger designs. Field Programmable Gate Arrays (FPGAs) contain thousands or millions of uncommitted gates and are almost ideal for large designs. The problem with FPGAs is that you have to learn a design language (Verilog or VHDL) and that in order to write even simple Verilog programs you need to set up a fairly complex development environment. It is the latter problem — the development environment — that this article addresses.

FPGAs at the Command Line

By Bob Smith

In this article, you'll see how to install the Xilinx FPGA design tools, how to use the Xilinx command line tools to compile a Verilog or VHDL design, how to download the compiled code to an FPGA board, and how to automate the whole process using a "makefile."

The Xilinx command line tools are the same for both Linux and Windows, making this article useful for almost anyone with a computer (including Mac users using a Linux virtual machine). The sample design for this article is a 28 bit counter which has the most significant eight bits visible on LEDs. It is counting transitions on a 12.5 MHz clock giving the least significant LED a flash rate of about 6 Hz. The circuit has a counter reset line tied to a button.

The hardware used herein is the Demand Peripherals Baseboard-2 which has a Xilinx Spartan-3E, LEDs, buttons, and a USB interface for

downloads and user data. Since the Baseboard-2 is downloaded through a USB serial port, it doesn't require the expense and complexity of a separate JTAG dongle or the hassle of installing JTAG drivers — and not requiring them is particularly nice for Linux developers. (I helped design the Baseboard-2 and one of our major design goals was to allow USB serial downloads.)

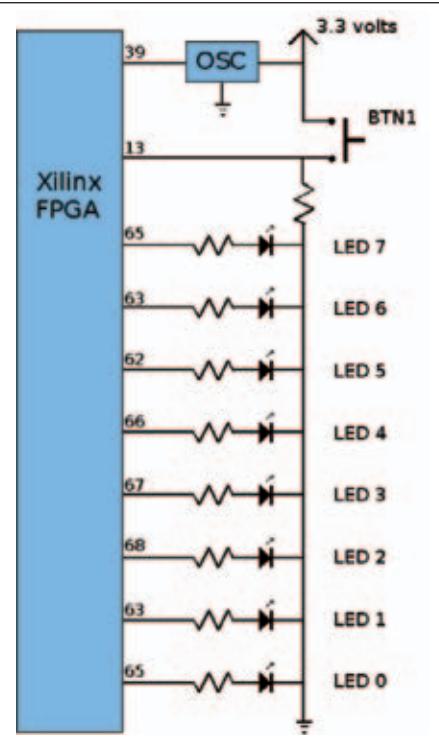
Installing the Xilinx WebPACK Toolkit

Xilinx provides a set of free design tools, the WebPACK, that runs on both Windows and Linux. Xilinx supports the tools on Windows XP Professional and on recent versions of Red Hat Enterprise Linux and SUSE Linux. While not officially supported, WebPACK runs fine on XP Home Edition, Vista, and Ubuntu. To get the tools working on your system, you have to go through about a dozen web pages to start the WebPACK

download, wait for a 2.2 GB download, and then go through another dozen or so screens for the installation. It is tedious, but straightforward.

Start by going to the Xilinx download site at: www.xilinx.com/support/download/index.htm. Skip the Search button and scroll directly down to click on the "Download ISE WebPACK" link. This will take you to a login page where you can select "Create Account" (since you probably don't already have a Xilinx account). You will receive an email message with a web link where you can go to finish the registration and to log in. After logging in for the first time, you're asked to provide more information. The Next button will take you to a screen that displays what Xilinx packages you are entitled to download. Select ISE WebPack10.1 and click on the Next button.

The next page — the Product Registration and Download page —



■ FIGURE 1. Baseboard-2 schematic.

has your registration ID. You might want to cut and paste this ID into a file for use in the installation, and in case you want to reinstall the package. This page also has several links for documentation and two links for downloading WebPACK. It is probably best not to click the large Download button as this tries to install software on your PC.

Instead, select the "Download Files Individually" link, and then select the Download link which appears next to the file size. The 2.2 GB download is going to take awhile even on a relatively fast Internet link.

The WebPACK download file is in a "tar" format, which – while common on Linux – is not well known on Windows. Windows users

■ LISTING 1. A User Constraints File for the Baseboard-2.

```

NET "CLEAR" LOC = "P13" ; # Button 1
NET "CK12" LOC = "P39" ; # 12.5 MHz clock
NET "LED<0>" LOC = "P70" ; # LED 0
NET "LED<1>" LOC = "P71" ; # LED 1
NET "LED<2>" LOC = "P62" ; # LED 2
NET "LED<3>" LOC = "P66" ; # LED 3
NET "LED<4>" LOC = "P67" ; # LED 4
NET "LED<5>" LOC = "P68" ; # LED 5
NET "LED<6>" LOC = "P63" ; # LED 6
NET "LED<7>" LOC = "P65" ; # LED 7

```

may need to install a package such as WinZip (www.winzip.com) or WinRAR (www.winrar.com), both of which can handle tar files.

Install the software by double-clicking setup.exe in the ZIP file or (for Linux) by untarring the download file and running the "setup" script in the top level directory. Windows users will need administrator privileges to install the software. The default installation directory on Windows is C:\Xilinx\10.1 and on Linux it is /opt/Xilinx/10.1. If installing on Linux as a non-root user, you might want to create /opt/Xilinx/10.1 beforehand and give yourself write permission on it.

The installation will ask if you want to do an immediate update and whether or not to install the cable drivers. Saying "yes" to an immediate update is a good idea but will trigger another 600 MB download. For this tutorial, you do not need the update and can safely postpone it. You can also say "no" to the "Install Cable Drivers" option since the board we're using does not need JTAG drivers. The installation takes 10 to 20 minutes once all the licenses are accepted and the installation options are set. Test the installation on Windows by opening a Command window and entering the command:

C:\Xilinx\10.1\ISE\bin\nt\xst -h.

On Linux, the command is:

/opt/Xilinx/10.1/ISE/bin/lin/xst -h.

If everything is installed correctly, you should see a display of the usage of the xst command. From this point on, I won't give the full path to the command. You should either prepend the full path to the command or modify your shell's execution path variable. A convenient way to do this on Linux is to source /opt/Xilinx/10.1/ISE/settings32.sh.

Creating a Simple Counter in Verilog

The Xilinx tools can compile either Verilog or VHDL and I've chosen Verilog for the test program. Whether it's VHDL or Verilog, you have to tell the compiler about the hardware on your FPGA board. The Xilinx "User Constraints File" contains these definitions. Figure 1 relates FPGA pin numbers or locations to logical names for use in the Verilog code. Consider, for example, this partial schematic of the Demand Peripherals Baseboard-2. The constraints file for this hardware might look like that shown in Listing 1. The NET field is the pin name as it appears in your Verilog program. The LOC field is the pin location on the physical FPGA. Xilinx specifies pin locations as the letter P, followed by the pin number on quad-flat packs, and by the grid location for parts in a ball grid array package.

The user constraints file can do much more than just relate Verilog names to pin numbers. It can also add pull-up or pull-down resistors, set output current limits, set timing constraints, and set output slew rate. Details about the user constraints file can be found on the Xilinx website by searching for "user constraints file." In particular, additional information is available in this document: <http://toolbox.xilinx.com/docsan/data/alliance/dev/dev3.htm>.

Use Notepad, vi, or your favorite editor to create a text file named counter.ucf and copy Listing 1 into it. (All three files for this article are available in the download section of the *Nuts & Volts* website (www.nutsandvolts.com).

The Verilog program for this tutorial implements a simple counter that counts an input clock and displays the high eight bits on the LEDs. A clear input can force the count to zero. Figure 2 illustrates the circuit for the Verilog design shown in Listing 2.

Copy the program shown in Listing 2 into a file called counter.v in your working directory.

Compiling Your Verilog Counter for Xilinx FPGAs

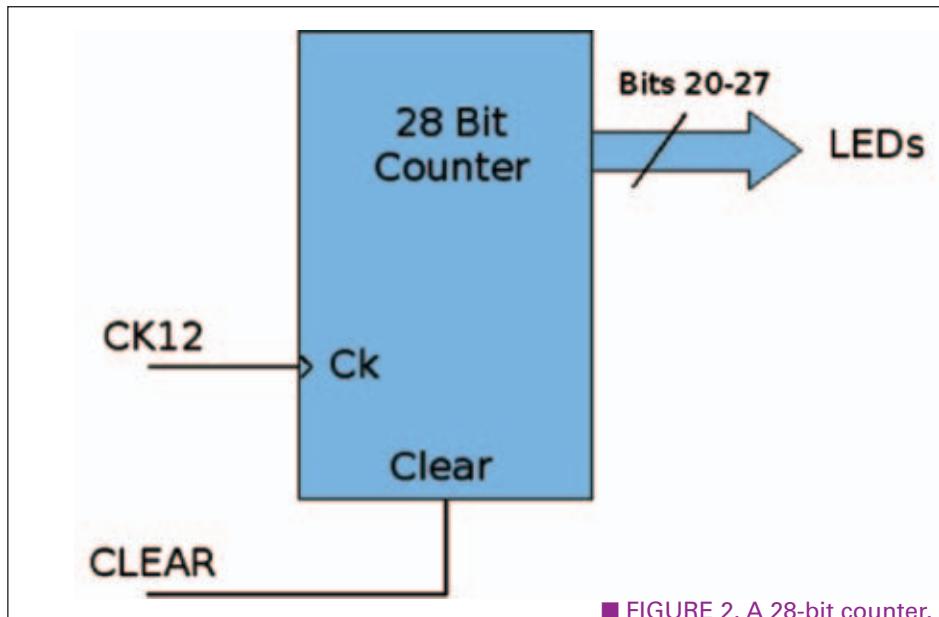
Xilinx provides a graphical development environment called ISE. You'll be issuing the same commands that ISE issues behind the GUI, but you'll be doing it from the command line. It is the use of command line tools that makes it easy to automate the build process in a batch file or a makefile. ISE leaves its configuration in several binary files in your working directory. Using just command line tools lets you clean the directory leaving only your original text files. Having just text files for your design makes it easier to use some type of version control, and to extract meaningful differences between two versions of a design.

There is insufficient space here to give detailed descriptions of the commands but your download of the Xilinx tools includes comprehensive manuals for the Xilinx command line tools. Look in ISE/doc/usenglish/books/docs/. The first command – xst – synthesizes the Verilog file into a hardware design that is saved as a netlist file with an .ngc extension.

Xilinx's xst program is actually a command line interpreter and it expects input from stdin. Use an echo command and a pipe operator to give xst input from stdin if you want to keep all of your build information in a makefile. The only difference between Windows and Linux for purposes here is in the echo command below Linux requires the quotes and Windows does not:

```
echo "run -ifn counter.v -ifmt Verilog -ofn counter -p xc3s100e-4-vq100 -opt_mode Speed -opt_level 1" | xst
```

You have to specify the input file, the input file format, the name of the output file, and the exact type of FPGA. If your goal is to learn VHDL and not Verilog, you can change the input format in the above command from "Verilog" to "VHDL," replace the 28 bit Verilog counter with its VHDL



■ FIGURE 2. A 28-bit counter.

equivalent, and continue reading the article as if it were about VHDL. Xst generates several report files and directories, but the real output is a netlist file with an .ngc extension that is required for the next command. You can examine the output files and reports to better understand how the synthesis works and an appendix in the xst manual describes the output files and reports in detail. The ngdbuild command further decomposes the design into FPGA native elements such as flip-flops, gates, and RAM blocks:

```
ngdbuild -p xc3s100e-4-vq100 -uc counter.ucf counter.ngc
```

It is the ngdbuild command that first considers the pin location, loading, and timing requirements specified in the user constraints file. Like the other Xilinx commands, ngdbuild produces several reports but its real output is a "Native Generic Database" stored in a (.ngd) file.

The Xilinx map command converts the generic elements from the step above to the elements specific to the target FPGA.

■ LISTING 2. Notecounter.v – a 28 bit counter in Verilog.

It also performs a design rules check on the overall design. The map command produces two files – a Physical Constraints File and Native Circuit Description – that are used in subsequent commands:

```
map -k 6 -detail -pr b counter.ngd
```

The map command produces quite a few reports. As you gain experience with FPGA design, you may come to rely on these reports to help identify design and timing problems. The place and route command (par) uses the Physical Constraints File and the Native Circuit Description to produce another Native Circuit Description file which contains the fully

```
module counter(CLEAR, CK12, LED);
    input CLEAR;           // Set counter=0
    input CK12;            // Clock source
    output [7:0] LED;      // Output display

    reg [27:0] count;     // a 28 bit counter
    reg metaclear;        // bring CLEAR into
                          // our clock domain
    always @ (posedge CK12)
    begin
        metaclear <= CLEAR;
        if (metaclear)
            count <= 0;
        else
            count <= count + 1;
    end
    assign LED = count[27:20]; // Set display
endmodule
```

routed FPGA design:

```
par counter.ncd parout.ncd  
counter.pcf
```

Output processing starts with the bitgen program which converts the fully routed FPGA design into the pattern of bits found in the FPGA after download:

```
bitgen -g StartUpClk:CCLK -g  
CRC:Enable parout.ncd counter.bit  
counter.pcf
```

The bitgen program lets you specify which clock pin to use during initialization and whether or not to generate a CRC checksum on the download image. Files which contain a raw FPGA download pattern are called bitstream files and traditionally have a .bit file extension. Bitstream files are good for downloads using JTAG but since we're downloading over a USB serial connection, one more command is required to convert the bitstream file into a download file:

```
promgen -w -p bin -o counter.bin -u  
0 counter.bit
```

The promgen program is a utility that converts bitstream files into various PROM file formats. The format for the Baseboard-2 is called bin so the promgen command uses the -p bin option. The output of

promgen – counter.bin – is what is downloaded to the Baseboard-2. All of the commands described above – including xst, ngdbuild, map, par, bitgen, and promge – have excellent PDF manuals in either the ISE/doc/usenglish/books/ docs/xst directory or the ISE/doc/usenglish/ de/dev directory of your WebPACK installation. Listing 3 is a Makefile that captures the commands and dependencies described above. Verilog does not lend itself to incremental compilation so just copying the above commands into a .bat file or a shell file is practically as good as using a makefile.

Downloading Your Counter to an FPGA Board

Now that you've compiled your Verilog program, you're ready to download it to the Baseboard-2. Since the Baseboard-2 is powered by a USB cable, it should be plugged directly into a USB port on your computer and not through a hub (unpowered). The Baseboard-2 uses an FTDI FT245 USB serial interface and you'll need the appropriate drivers for your operating system. Figure 3 shows the Baseboard-2 powered by USB. You can clearly see the Xilinx FPGA in the center of the board. The IC to the left is the FT245 and the smaller IC to the lower left is a Xilinx CPLD that coordinates the download between the FPGA and the USB interface.

On Windows, you can plug the board in and you'll be prompted with the usual "New Hardware Found" message. After loading the Windows driver for the FT245, you may be asked to load a driver for a USB serial port. Looking at the System folder in the Control

Panel will show which COM port was assigned to the USB serial port. On my system, it was assigned to COM5 so I'll use that for the example. The Windows command to download the compiled Verilog code is just:

```
copy counter.bin COM5:
```

Linux ships with a driver for the FT245 and it will be loaded automatically when you connect the Baseboard-2 to your system. Ubuntu users should watch for a bug in which the device driver for a USB Braille reader interferes with all USB serial ports.

On my system, the FTDI USB serial port is assigned to /dev/ttyUSB0. Linux does what is called post processing on data sent to a serial port and you need to turn this off to prevent it from corrupting your download file. The two commands needed to download the compiled Verilog code on Linux are:

```
stty --file=/dev/ttyUSB0 -opost #  
No post processing  
cat counter.bin > /dev/ttyUSB0
```

Are the LEDs incrementing? If so, congratulations! You're on your way into the world of FPGA programming with Verilog! Most FPGAs lose their programming when powered down and most boards – including the Baseboard-2 – are ready for download immediately at power-up. You can also press the reset button to get the board ready for another download. While not a requirement, it is considered "polite" to disable a USB device under Windows before you unplug it:

Dealing with JTAG

The Demand Peripherals Baseboard-2 and the XESS XSA-3S1000 are two examples of FPGA boards that do not require JTAG for code download. Dealing with JTAG at the command line is possible, but a common problem – especially for Linux users – is first finding and installing the device driver that



■ FIGURE 3. Baseboard-2 downloaded from and powered by USB.

matches the JTAG dongle that you buy. JTAG drivers are more standard and easier to install on Windows, and for this reason many would-be Linux FPGA developers move to Windows for FPGA development. I know one Linux user who does all of his development on Linux and then copies his files to Windows for the JTAG downloads.

The Xilinx command to manage JTAG devices and downloads is named impact. It is a command line interpreter similar to xst, and its internal commands and options are described in full in Appendix C of the iMPACT User Guide at <http://toolbox.xilinx.com/docsan/xilinx4/data/docs/pac/preface.html>. Xilinx compatible JTAG dongles are available from several commercial sources, and Appendix B of the iMPACT User Guide even has a schematic of a simple JTAG dongle that attaches to a legacy parallel port.

The sub-commands to use inside iMPACT can vary a great deal depending on the type of FPGA board that you are using. I've found that the easiest way to deal with impact is to run ISE and invoke the GUI interface to impact the first time I download to a board, and then extract the impact sub-commands from the _impact.log file.

Using this technique on the SparkFun Spartan 3E Breakout and Development Board gives an iMPACT command of impact -batch impact.bat where the batch file is:

```
setMode -ss
setMode -sm
setMode -hw140
setMode -spi
setMode -acecf
setMode -acemp
setMode -pff
setMode -bs
setCable -p auto
addDevice -p 1 -file
counter.bit
Program -p 1 -
defaultVersion 0
Quit
```

Note the addDevice -p 1 sub-command in the above batch file. JTAG devices are usually arranged as a string of devices and the addDevice sub-command specifies which device in the chain of devices to program or examine. Some manufacturers (such as Digilent) prefer PROMs that can be programmed directly from JTAG. Other manufacturers (such as SparkFun) have you use JTAG to load an FPGA program that then reads from a serial port, burning the received bytes into the PROM. The Baseboard-2 is meant to be connected to a PC, and since a download to the Baseboard-2 takes less than 100 milliseconds, it hardly seemed necessary to add a PROM and force the user into the cost and driver issues associated with JTAG.

Conclusions and Next Steps

In this article, I focused on two

things: expressing your design as text files and using just a few standard commands to compile and download your design. Having your design in text files will make it easier for you to track changes and will make it easier for you to add version control for your projects.

Using command line tools can be faster and is a nice way to better understand the steps to convert a design from Verilog to a bitstream file. Even if you switch to a GUI-based approach later, at least you now have more appreciation for what is actually going on.

You may have noticed another purpose in this article. It is an attempt to get a working Verilog program as few steps as possible. I meant this article to be something of a "Hello, World!" program for Verilog. The next steps are, of course, up to you. Here, we just got the tools working; we didn't even scratch the surface on real Verilog design. My advice for you is to select and buy two or three Verilog (or VHDL) books and read them cover to cover.

Before leaving this project completely, let's see if you can make a few simple modifications to the program. Say Button 2 is on pin 30 and that Button 3 is on pin 69. What would you have to do to the .ucf file to add Button 2 as a "Hold" button and Button 3 as a "Direction" button? What would you have to do to the Verilog file to make the count freeze while Hold is being pressed? What would it take to make the counter count down while Direction is being pressed?

Your wish is in your command lines! NV

```
# Makefile to compile and download a simple Verilog program

DEVICE=xc3s100e-4-vq100
default: counter.bin

counter.ngc: counter.v
    echo "run -ifn counter.v -ifmt Verilog -ofn counter -p \
$DEVICE -opt_mode Speed -opt_level 1" | xst

counter.ngd: counter.ngc counter.ucf
    ngdbuild -p $DEVICE -uc counter.ucf counter.ngc

counter.ncd: counter.ngd
    map -k 6 -detail -pr b counter.ngd

counter.pcf: counter.ngd
    map -k 6 -detail -pr b counter.ngd

parout.ncd: counter.ncd
    par counter.ncd parout.ncd counter.pcf

counter.bit: parout.ncd
    bitgen -g CRC:Enable -g StartUpClk:CCLK -g Compress \
parout.ncd counter.bit counter.pcf

counter.bin: counter.bit
    promgen -w -p bin -o counter.bin -u 0 counter.bit

install: counter.bin
    stty --file=/dev/ttysB0 -opost # We want raw output
    cat counter.bin > /dev/ttysB0

clean:
    rm -rf counter.bgn counter.bin counter.bit counter.bld \
counter.drc counter.map counter_map.xrpt counter.mrp \
counter.ncd counter.ngc counter.ngd counter_ngdbuild.xrpt \
counter.ngm counter_par.xrpt counter_pcf counter.prm \
counter_summary.xml counter_usage.xml counter_xst.xrpt \
netlist.lst parout.ncd parout.pad parout_pad.csv \
parout_pad.txt parout.par parout.ptwx parout.unroutes \
parout.xpi xlnx_auto_0 ise xlnx_auto_0_xdb xst
```

■ LISTING 3. A Makefile for Xilinx command line tools.

POWER MOSFETs

Part 2: Projects

Last time, we examined how to use power MOSFETs. This time, we'll build two projects. The first is a transformerless voltage doubler that takes a DC voltage from 12 to 30 volts and doubles it. Unlike most other voltage doubler circuits, this design can supply amps of current. It incorporates a high-efficiency, full-bridge design that has additional applications such as a motor driver, power inverter, or even a Class D power audio amplifier.

The second project uses a power MOSFET in a linear (rather than switching) application. A simple constant current power supply is presented. With proper heatsinking, it can supply up to 20 amps. Each project can be built at a basic parts cost of about \$15.

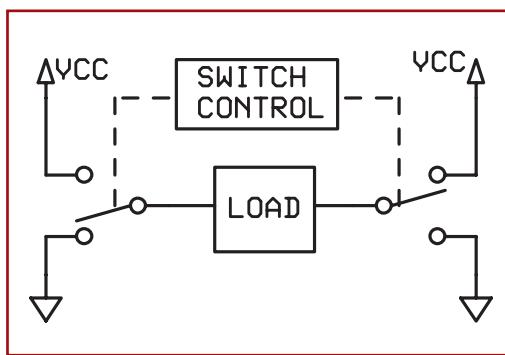
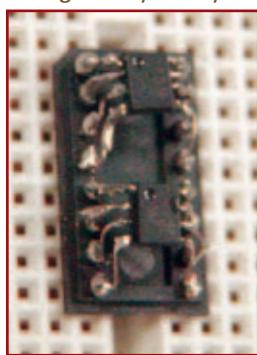
by Gerard Fonte

The H-bridge

The voltage doubler is based on a standard H-bridge design, shown in Figure 1. Basically, an H-bridge functions as a DPDT switch which reverses the polarity to a load. There are many applications for this circuit such as switching power supplies and motor control. Without getting into the details, switching at high speed gives good motor control and very efficient power supplies. The high frequency allows the use of smaller inductors and capacitors which can significantly reduce size, cost, and weight.

Our H-bridge is shown in Figure 2. It consists of several simple building blocks. The first is a regulated power supply (U1 and associated components).

PHOTO 1. I made a DIP adapter for the surface mount drivers from a "component carrier." The large solder blobs on the carrier pins act as a heatsink when soldering to the driver chip. Once one pin is soldered, the rest go fairly easily.



This is needed because other circuits may not be able to function over the full input range of the circuit. A three-terminal regulator is chosen to provide a stable 10.5 volts. Any voltage from 10 to 12 volts is fine for the low-power circuits.

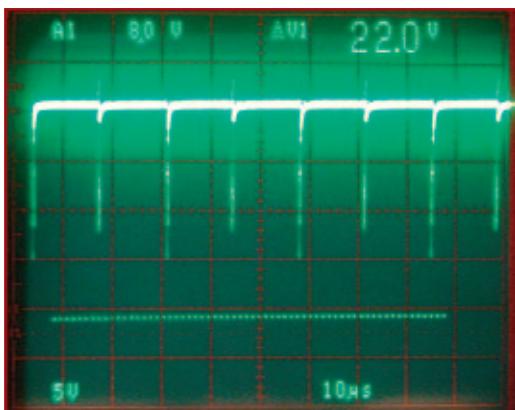
Generally, you want to keep it over eight volts for proper boot-strap operation (see Part 1). The other low voltage parts like to see something at 15 volts or less. A fixed 12 volt regulator (LM7812) can also be used here. The second part is the master clock (U2 and associated parts) and is a simple 555 oscillator with a twist. As shown, it provides a very precise 50% duty cycle with a frequency of about 35 kHz. The twist is that the output pin is NOT used for the charging and discharging of the timing capacitor, as is the case for most other 50% duty cycle designs. This makes the circuit completely insensitive to output loading. Additionally, those other "50%" designs are more typically 45%-55%, or worse. Note that I verified proper operation with bipolar, CMOS, and low power 555 timer versions. A 50% duty cycle is not an absolute requirement for this design, but it distributes the power evenly through both halves of the bridge.

A DPDT switch makes and breaks contacts simultaneously (in theory). Since we are using N-channel parts for both the high side and low side, we will have to use a two phase clock. That is, both a "clock" signal and an "inverted clock" signal must be available. A CMOS 4069 inverter (U3) is used to invert the 555 signal. I chose to use separate inverters because they were available. You could run the Q signals directly from the 555 and the /Q inverted signals from a single inverter if desired.

As noted in Part 1, getting the power MOSFETs to switch quickly is not a trivial task. For that reason, I used special driver chips for this part of the circuit (U4 and U5). The LM5109 are inexpensive and easy to use. They provide a peak

FIGURE 1. Conceptually, an H-bridge is just a double-pole, double-throw switch that reverses the polarity of the power to the load.

■ PHOTO 2. The output directly from the voltage doubler (without filtering) shows a DC signal with switching glitches. The simple filter shown in Figure 3 reduces these glitches to about 200 mV.



current of one amp to the gate of the MOSFET and typical switching times of 15 ns into 1,000 pF. They can support MOSFETs operating at up to 90 volts and can supply a bootstrap voltage of up to 108 volts. The Schmitt trigger inputs accept TTL and CMOS level signals.

Unfortunately, these drivers do not come in standard DIP packaging. I had to get SMT parts and fabricate an adapter as shown in Photo 1. It requires a steady hand with the soldering iron but is not too difficult. The trick is to put the component carrier in a protoboard (as shown) to support it and act as a heatsink for the pins. Put a blob of solder on a carrier pin and use #30 solid wire. Solder the carrier first because it acts as a heatsink. If you solder a wire to the SMT driver pin first, it may become unsoldered when you solder the wire to the carrier pin. Be careful with the heat because the carrier is made of thermoplastic and melts.

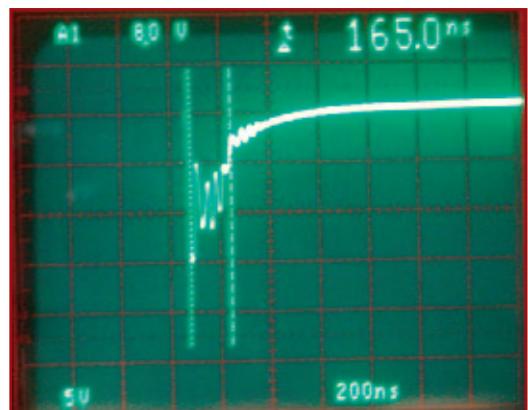
Last part of the circuit is the power MOSFETs themselves. I chose IRF540 devices. They cost about \$0.75 each, operate up to 100 volts, and can handle 28 amps continuously with an on resistance of 0.77 ohms. In theory, this design can handle 2,500 watts of power. We won't be anywhere near that value.

The input voltage is limited to 30 volts because the voltage regulator that supplies power to the timer and other circuits is only rated at 35 volts. If you use a separate low-voltage power supply, the input can be theoretically increased to 90 volts where the driver chips fail. More realistically, the maximum safe input to the H-bridge is about 75 volts as shown.

The maximum continuous DC current — derated for heating — is about 14 amps for the MOSFETs. Since each MOSFET is on only 50% of the time and the switching speed is high, a full 28 amps through the bridge is a reasonable figure. Note that each MOSFET will have to dissipate 50 to 60 watts in this scenario, so good heatsinking will be a requirement.

Output Circuits and Variations

We will be using a simple capacitor voltage doubler, shown in Figure 3. It connects directly to the output of Figure 2. (In addition to the H-bridge outputs, connections to H-bridge power and ground are required.) Note that the doubled output voltage is theoretically a perfect DC signal right out of the bridge rectifier. In practice, switching glitches are present and can usually be removed with a



■ PHOTO 3. The switching glitch is about 165 ns. This can be reduced or eliminated with proper fine tuning of the switching signals.

simple filter as shown. The capacitor ratings in this voltage doubling circuit are critical. The use of improper capacitors can cause them to explode. (See the sidebar on Switching Capacitors for details.) Because of this failure possibility, it is strongly recommended that the project be housed in a sturdy box. Since the box only has input and output jacks, there seems little reason to show it.

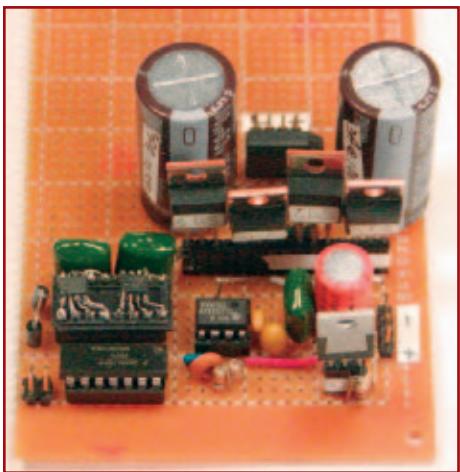
If you want to do something other than voltage doubling, you can use Figure 4's circuit. It's more conventional and easier to understand. Just remember that the switching frequency is 32 kHz, so ordinary 60 Hz transformers are marginal performers. (Of course, you can always change the circuit's frequency.) A toroidal transformer is usually incorporated here. Generally, they provide better efficiency and high frequency performance. I tried an ordinary 60 Hz power transformer and got

Bridge Power Ratings

In theory, a bridge circuit can provide up to four times more power to the load than a standard power control circuit. This seemingly impossible task is accomplished fairly directly and logically. However, it is a bit subtle. Suppose you have an ordinary audio amplifier running at eight volts and driving an eight ohm speaker. The voltage swing at the speaker will be a maximum of ± 4 volts. Four volts into eight ohms is 0.5 amps. The peak output power is then two watts ($\text{Power} = \text{Current}^2 \times \text{Resistance}$).

However, a bridge circuit changes the polarity to the load. This results in eight volts going in one direction and 8 volts going in the other direction for a ± 8 volt swing. Doubling the voltage causes twice the current to flow, or one amp. Doubling the current results in four times as much power ($P=I^2 \times R$). So, a bridge amplifier can provide up to four times as much power (eight watts) to the load as a non-bridge type.

The next question is why bridged power amplifiers are only rated at twice the non-bridged power, or less. This is because of the power handling of the amplifier rather than the theoretical power delivered to the load. If one amplifier can only dissipate enough heat to support X watts of power output, then two amplifiers can still only dissipate 2X watts, regardless of the voltage swing.



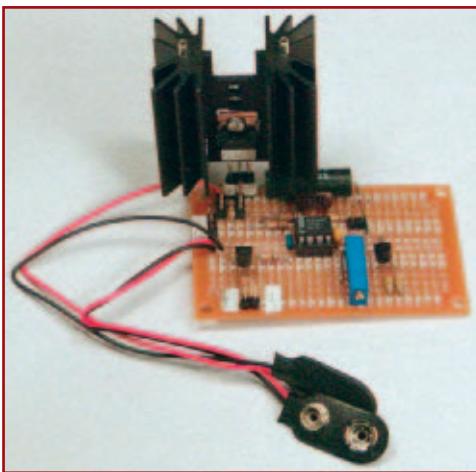
■ PHOTO 4. The breadboard of the voltage doubler (without filter). This is placed in a sturdy enclosure for safety (not shown, see text). Use short wires because the switching speeds are high.

reasonable results (considering the input was a square wave). Obviously, be sure your transformer is rated properly for current and voltage. Output filtering is required and is dependent on the frequency, transformer, and load.

A motor can be directly connected to the H-bridge. For optimal performance, you will want to be able to independently control the legs of the bridge. This cannot be done with a fixed oscillator. Instead, the Q and /Q signals should be adjustable. By changing the phase and pulse width, the motor's direction and speed can be controlled with precision. As noted above, if you want to use this H-bridge as a motor controller you should pay close attention to possible voltage and current spikes.

You can always use the H-bridge as an audio amplifier by attaching a loudspeaker to the output. This would be a "Class D" design where pulses are applied to the speaker. Again, the pulses would have to be precisely controlled, typically by a microcontroller. The high frequency pulses have to be filtered out to provide a low distortion audio signal. For good audio, the switching frequency should probably be increased to about 100 kHz. A Class D amplifier using this H-bridge has the potential of providing kilowatts of audio power (see the sidebar on Bridge Power).

Lastly, the circuit shown here operates at a nominal 35 kHz. By changing the timing capacitor in the 555 circuit, other frequencies can be obtained. There is a trade-off, however. The higher the frequency, the greater the switching losses. The capacitors



■ PHOTO 5. The breadboard of the constant current supply. Since the MOSFET is acting as a variable resistor, considerable heat is generated. A heatsink is required.

and inductors (if used) can be smaller, though, which saves money and space. Additionally, the higher the operating frequency, the greater the likelihood of EMI (Electro-Magnetic Interference). Clearly, when you are switching kilowatts of power, you have to be concerned with unintentional RF (Radio Frequency) emissions. The square waves – so essential for efficiency – contain loads of higher frequency harmonics.

The Voltage Doubler Details

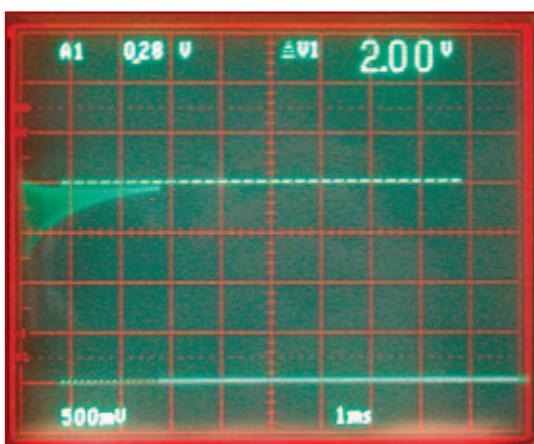
The design concept was to provide a simple voltage doubler for basic DC power supplies. In particular, I had a 0-30 volt, three amp supply. There are occasions when I needed a higher output voltage. Making the H-bridge voltage doubler is simplicity itself. Just connect two capacitors and a bridge rectifier as shown in Figure 3. The output will be a pretty good DC signal as shown in Photo 2. Only 165 ns switching glitches are present (photograph 3). These glitches can be reduced to about 200 mV with the optional output filter.

Note that these glitches can be significantly reduced or even eliminated by fine-tuning the switch timing. Some driver chips allow this. Alternatively, you could use a microcontroller or dedicated digital hardware for better switching control.

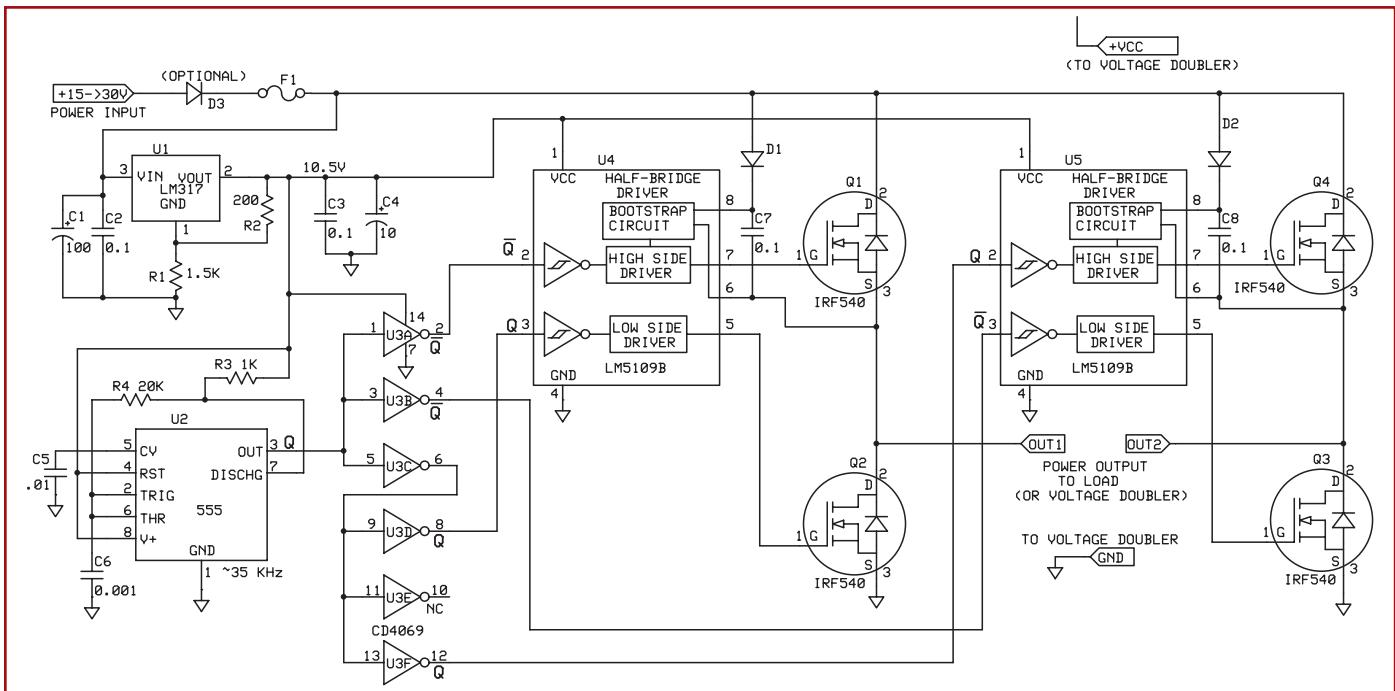
Photo 2 shows that there are 22 volts out of the circuit with a 12 volt input. The circuit load was a 68 ohm resistor which pulled about 1/3 of an amp and dissipated over seven watts of heat. The MOSFETs weren't even warm. However, the bridge rectifier got quite hot because it was deliberately under-rated (will discuss shortly).

Photo 4 shows the breadboard of the voltage doubler.

It's important to keep things as close together as practical. Long leads with high frequencies can result in poor performance. Note that heatsinks for the MOSFETs are not needed for this typical operation of a few amps. I did not include the fuse because I will always be using it with a current-limited power supply. If you do not use such a supply, you should use a slow-blow fuse about 300% above the highest current output you expect. For example, if you power a device that draws one



■ PHOTO 6. With a load of 0.1 ohms, this two volt signal means that 20 amps are flowing. The ringing is because the feedback loop was opened (see text).



amp, use a three amp input fuse. This is because you will need more than twice the input current. The input diode (D3) is optional and is used to prevent damage if the input power is accidentally reversed. It will reduce the efficiency of the circuit. Make it about 10 times the expected output current with a PIV (Peak Inverse Voltage) of at least twice the maximum input voltage.

The major loss of power in the circuit is in the bridge rectifier. There is about 1.4 volts dropped across it. With an input voltage of 14 volts, at least 10% is lost here. With only one amp of current, it will have to dissipate 1.4 watts of power. For better heat control and efficiency, I recommend well oversized and separate diodes of 10-15 amps

FIGURE 5. The analog constant current circuit is quite simple. A heatsink for the power MOSFET is required. For continuous use, R9 and Q2 can be omitted and R6 replaced with a wire.

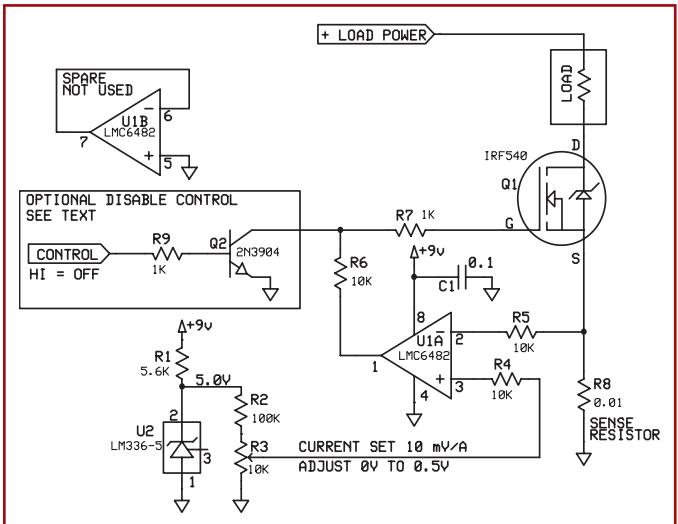


FIGURE 2. The basic H-bridge circuit. The power MOSFETs act as the DPDT switch. The control chips provide the proper gate voltages; the timer and inverter create the clock signals; and the voltage regulator sets a fixed voltage for the low voltage components.

each with a heatsink (see Parts List). Using lower current diodes causes considerable heating which further increases the forward voltage drop. This causes even more heating and greater forward voltage drop, and so forth and so on. Losses can more than double if too small diodes are used. (Note that I only used a two amp bridge because I have a specific application that uses little power.)

FIGURE 3. The voltage doubler circuit connects to the basic H-bridge (Figure 2) at four points. The output is close to a DC signal but switching glitches will be present. The optional filter (L2 and C3-C5) reduces the noise to about 200 mV.

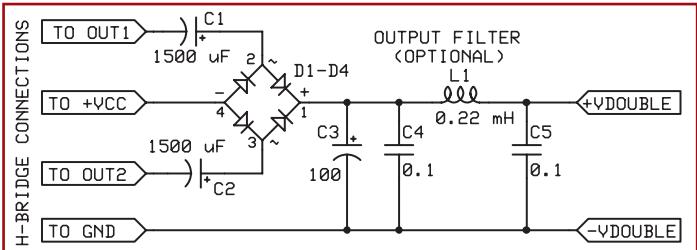
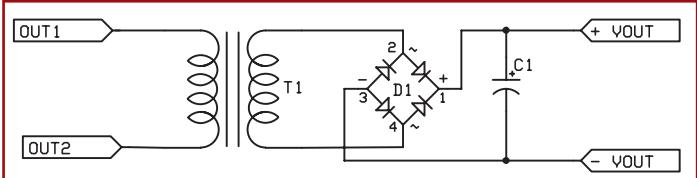


FIGURE 4. You can use a transformer to generate almost any voltage you want. The square wave input will require considerable output filtering, depending on the application. The transformer type and switching speed also have significant effects.



Constant Current Supply

Power MOSFETs can be used in linear applications, as well. In such cases, they are typically treated as variable

CONSTANT CURRENT SUPPLY PARTS LIST

Resistors 1/4, 5% unless specified.

<input type="checkbox"/> R1, R9	5.6K
<input type="checkbox"/> R2	100K
<input type="checkbox"/> R3	10K 10-turn trimmer
<input type="checkbox"/> R4, R5, R6	10K
<input type="checkbox"/> R7	1K
<input type="checkbox"/> R8	0.01Ω 5W (Mouser #588-15FR010E)

Capacitors

<input type="checkbox"/> C1	0.1 μF 25 volts
-----------------------------	-----------------

Semiconductors

<input type="checkbox"/> Q1	IRF540 Power MOSFET (Jameco)
<input type="checkbox"/> Q2	2N3940 NPN transistor
<input type="checkbox"/> U1	LMC6482 Op-amp
<input type="checkbox"/> U2	LM336-5 Five-volt reference

Misc: Heatsink for Q1

resistors which imply considerable heat losses. Proper heatsinking is necessary. Nevertheless, these devices allow you to control high power quite easily.

Figure 5 shows a simple constant current power supply. The theory of operation is very basic. A small voltage is developed across the 0.01 ohm sense resistor (R8) and is fed into the inverting input of the op-amp. This positive voltage is inverted by the op-amp, reducing the output voltage which reduces the voltage across the sense resistor via the MOSFET. This stabilizes the output voltage to the value found at the non-inverting input. Any change in current through the sense resistor causes a voltage change at the inverting input which is exactly offset by the negative feedback. The result is a constant current through the sense resistor and load.

Determining the reference voltage to be applied to the non-inverting input is just an application of Ohm's Law. If there is one amp of current flowing through the 0.01 ohm sense resistor, there will be 0.01 volts across it. So, the voltage-to-current ratio is 1:100 or 0.01 volts per amp.

The reference circuit is pretty straightforward. We want a stable and adjustable voltage from 0.0 volts to about 0.500 volts. I used an LM336-5 five volt reference because that is what I had on hand. Then, I reduced voltage with a resistor network and used a 10 turn trimmer for fine adjustment.

Other methods of generating the reference voltage can be used, as well. (You can substitute an analog signal for the reference voltage and get a constant current power amplifier.)

There are a few considerations for this circuit. The first is that separate power supplies should be used for the load and circuit power. This is because it's very easy to cause significant power supply variations with 20 amps of current being drawn. If you choose to use a different op-amp, be sure it can operate with inputs very close to ground. The breadboard circuit is shown in Photo 5. The heatsink shown (a requirement) is rated at 13 watts. You may need a larger one for continuous use at 20 amps, depending on the load resistance. Remember that the MOSFET is acting like a resistor in this circuit. Depending on the load, its resistance can be relatively high or low and its power dissipation can be correspondingly high or low. Do the math to be sure. Note that at 20 amps, the five watt sense resistor (R8) dissipates four watts. If you plan on running this continuously at high current, you may want to increase R8 to seven or 10 watts.

Because of the very low sense resistance, ordinary circuit resistance can increase this significantly. (My circuit resistance was 30 milliohms.) The primary concern is that the voltage at the non-inverting input will be higher than expected (one amp per 13 mV rather than 10 mV). In most cases, this is not a problem for the proper operation of the circuit.

BASIC H-BRIDGE PARTS LIST

Resistors (1/4W, 5% unless specified)

<input type="checkbox"/> R1	1.5K
<input type="checkbox"/> R2	200
<input type="checkbox"/> R3	1K
<input type="checkbox"/> R4	20K

Capacitors (25V unless specified)

<input type="checkbox"/> C1	100 μF
<input type="checkbox"/> C2, C3	0.1 μF
<input type="checkbox"/> C4	10 μF
<input type="checkbox"/> C5	0.01 μF
<input type="checkbox"/> C6	0.001 μF
<input type="checkbox"/> C7, C8	0.1 μF 150V

Semiconductors

<input type="checkbox"/> D1, D2	1N4004
<input type="checkbox"/> D3	Optional, see text
<input type="checkbox"/> Q1-Q4	IRF540 Power MOSFET (Jameco 210518)
<input type="checkbox"/> U1	LM317 adjustable voltage regulator
<input type="checkbox"/> U2	555 timer
<input type="checkbox"/> U3	CD4069 CMOS hex inverter
<input type="checkbox"/> U4, U5	LM5109B half-bridge driver (Digi-Key)

Misc.

<input type="checkbox"/> F1	Slow-blow fuse (see text)
<input type="checkbox"/> Case	Metal preferred for safety and EMI reduction (see text)

Additional parts for H-bridge Voltage Doubler (see text)

<input type="checkbox"/> C1*, C2*	1,500 μF 63 volt switching capacitor (Mouser #647-UPW1J152MHD)
<input type="checkbox"/> D1-D4	15 amp rectifier (Jameco #879318)
<input type="checkbox"/> C3	100 μF 150 volts (optional, see text)
<input type="checkbox"/> C4, C5	0.1 μF 150 volts (optional, see text)

* Critical part, safety related, see text.

Since I didn't want to continuously run 20 amps while testing and for photography, I used a quick and dirty method of turning off the circuit. I simply used a transistor to pull the MOSFET gate to ground. This worked, but opened the feedback loop. As a result, when the transistor was turned off and normal linear operation was restored, there was considerable ringing as the loop re-stabilized. (If you don't want the disable control, you can eliminate R9 and Q2, and replace R6 with a wire.)

Photo 6 shows the circuit in operation. It is providing just about two volts into a 0.1 ohm load using a 14.4 volt portable tool battery. Thus, the current is about 20 amps. Not bad for a handful of components. In this 5% duty-cycle application, the heatsink was barely warm.

Conclusion

Power MOSFETS can control a lot of power easily. An H-bridge voltage doubler circuit was seen to be suitable for this design, as well as other applications. An analog constant current project was able to easily provide 20 amps into a 0.1 ohm load. A nice feature of power MOSFETS is that if even higher currents are needed, they can be paralleled very easily. In short, power MOSFETS are an inexpensive and easy way of controlling significant power. **NV**

Switching Capacitor Ratings

It is extremely important to pay close attention to capacitor ratings in power switching circuits. These designs place a severe strain on the capacitor and it must be rated for this type of operation. Using the wrong type of capacitor can result in the capacitor exploding. Often, switching capacitors are chosen because of these other ratings rather than its capacitance. The two most important ratings to consider are: ESR and ripple current (typically at a switching frequency of 100 kHz). The ESR (Effective Series Resistance) says how much resistance the capacitor has. Ideally, a charge on one capacitor plate should freely interact with the other plate. But, capacitors 1 to 0.01 ohms. Everything else being equal, usually the larger the capacitor value is, the lower the ESR will be. So, if you are driving a heavy load (say a two ohm loudspeaker), a one ohm ESR will waste a lot of power and heat up the capacitor.

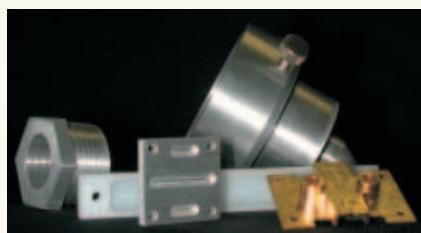
The second rating is the ripple current. This says how much RMS current can safely pass through the capacitor continuously. Again, typically, the larger the capacitor value, the higher current it can handle.

These capacitors usually fail because heat degrades the capacitor and increases the ESR. This causes a larger voltage drop across the capacitor and additional heating. Eventually, the capacitor gets too hot and bursts. This bursting can be mild or explosive. Most capacitors have relief points that reduce the chances of a violent explosion, but care should always be taken. Always house these types of circuits in a sturdy cabinet.

Complete Fabrication Center

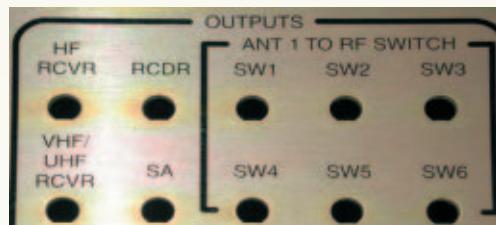
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A Touch of Spice

PART 3

by Peter J. Stonard

Most SPICE work stimulates a proposed circuit with a pulse or sine wave signal. In this final part, we'll look at oscillator circuits that *create their own signal* during simulation in LTspice, plus a "hollow state" oscillator, just for fun!

Following the earlier articles, you probably have LTspice on your computer's desktop, ready to use. So, we'll jump right in with a simple sine wave oscillator.

Oscillator Circuits

Recall that an oscillator is a circuit with amplification and frequency selectivity components. The old joke goes that "my amplifier oscillates, but my oscillator doesn't." An oscillator needs an amplifier with a feedback path from output back to the input that replaces energy lost in both the feedback network and the load. The feedback network selects the resulting output frequency. Another name for this arrangement is *Harmonic Oscillator*, as noted in Wikipedia at: <http://tinyurl.com/lwpe7>. For a low distortion sine wave, two distinct feedback paths are required, as illustrated in Figure 1.

The *positive feedback path* builds the output and defines the frequency, while the *negative feedback path* controls the gain to cancel all the losses.

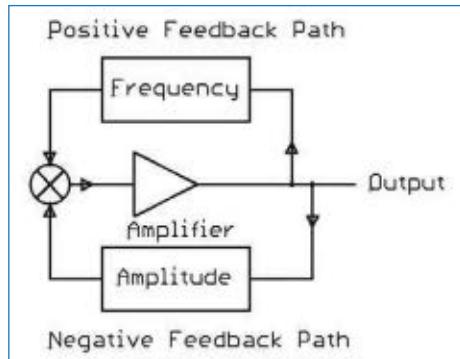
Many of these basic oscillators are named for their inventors, and may use inductor-capacitor (LC) or resistor-capacitor (RC) networks for frequency control. Perhaps you've already found the examples bundled

with the LTspice download; these include several oscillator designs. Use your computer's file directory tree to find them. Figure 2 is a list of oscillators circuits; there are more files in the download bundle.

Phase Shift Sine Wave Oscillator

A popular and easily constructed sine wave oscillator uses the phase shift in a chain of capacitor-resistor (CR) stages to define the frequency. The circuit starts automatically due to inherent noise in the amplifier, and after a few cycles it stabilizes on frequency.

Each CR stage contributes 60 degrees of the 180 degree phase shift needed, and attenuates the signal by one half. So, the theoretical amplifier voltage gain is: $1 / (1/2 * 1/2 * 1/2) = 8$ (or 18dB). The frequency is defined as $1.73 / CR$ (assuming all of the C and all of the R timing elements are the same value). By isolating the three phase shift stages from each other



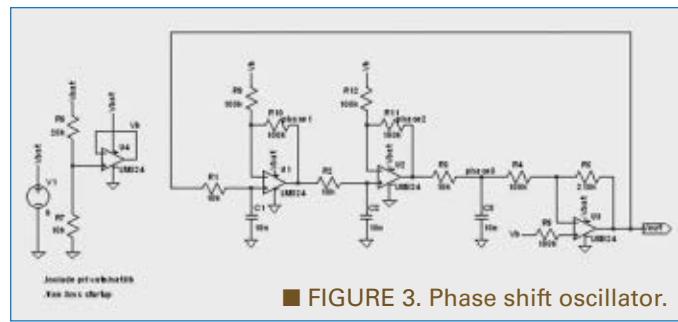
■ FIGURE 1. Oscillator basics.

with buffer amplifiers, we can see what is happening at each one. The LTspice schematic is shown in Figure 3 and the simulation waveforms are in Figure 4. Notice the SPICE directive **.tran 3ms startup?** This tells LTspice to start the power supply (our 9V battery equivalent) at zero volts and collect data for 3 ms, showing us how this circuit starts up. Also notice in Figure 4 the output shoots up and hits the supply rail, followed by a few cycles of correction as the oscillator comes into balance.

I built this circuit on a solderless breadboard (shown in Figure 5) using two dual op-amps (LM1458) and some 10K and 100K 1/4W resistors. The results are shown in Figures 6 and 7. Luckily, my scope can display all three

■ FIGURE 2. LTspice supplied oscillators.

Address: C:\Program Files\LT\LTspice\Schematics\Educational				
Folders:	Name	Size	Type	Date Modified
• iTunes	astable.asc	2 KB	LTspice Schematic	11/6/2008 11:46 AM
• Jasc Software Inc	Clapp.asc	2 KB	LTspice Schematic	7/23/2008 3:21 PM
• Java	colpits2.asc	2 KB	LTspice Schematic	7/23/2008 3:21 PM
• Ibr	colpits.asc	2 KB	LTspice Schematic	7/23/2008 3:21 PM
• Logitech	Hartley.asc	3 KB	LTspice Schematic	7/23/2008 3:21 PM
• LTC	phaseshift2.asc	2 KB	LTspice Schematic	7/23/2008 3:21 PM
• SyxCADIII	phaseshift.asc	3 KB	LTspice Schematic	7/23/2008 3:21 PM
• examples	Pierce.asc	4 KB	LTspice Schematic	7/23/2008 3:21 PM
• Educational	Wien.asc	3 KB	LTspice Schematic	7/23/2008 3:21 PM



■ FIGURE 3. Phase shift oscillator.

phase waveforms at once, where we can see the 60 degree phase shifts. To get it to work, I had to raise the voltage gain slightly (my R5 is now 233K). If you build one, add a 50K preset trimmer in series with R5. Mine oscillated at 2.928 kHz against a theoretical 2.768 kHz. The errors are probably due to random component selection and the construction method, and the scope traces for the 'middle stages' are a bit distorted.

In summary, the phase shift oscillator produces nice sine waves where the frequency is set by the time constant of the RC sections. The output amplitude is regulated by the non-linear gain of the amplifiers which occurs with all amplifiers when the signal drives their output near to either ground or the supply.

Many analog oscillator circuits use a variable gain element (FETs are popular) to regulate the gain and maintain a low distortion sine wave output. Traces are: Phase 1, Phase2, and Output; Y = 500 mV/div, X = 50 µs/div.

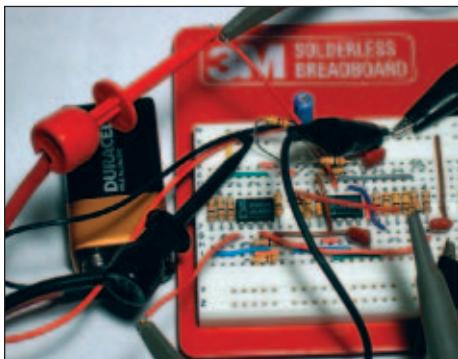
The LTspice and other files for this session are zipped together and available for download from the Nuts & Volts website www.nutsvolts.com.

Digital Oscillators

Digital circuits require the "marking of time" with a pulse rather than low distortion sine waves; simple oscillators constructed from analog circuits can produce pulses compatible with digital gates.

For two interesting analog oscillator circuits that produce pulses,

■ FIGURE 5. Phase shift oscillator breadboard.



check out the examples bundled with the LTspice download. Astable.asc is a two transistor astable oscillator, and LM555.asc is a nice transistor level Macromodel of the popular 555 timer IC. Both are included in the download for this session, and I encourage you to have some fun with them in LTspice!

Using Digital Logic Gates as Oscillators

One other interesting approach is to make digital logic components operate in the analog realm. Just a few components make an oscillator and these can include a crystal for high accuracy and stable frequency control.

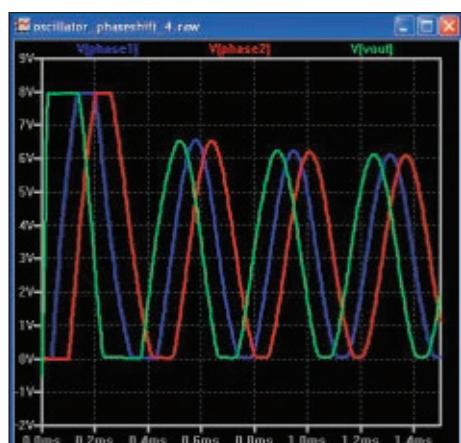
It's easy to get a basic CMOS inverter logic gate to act as an amplifier by placing a high value resistor of several megohms from output to input. This biases the gate as an inverting amplifier, but usually causes the gate to oscillate due to stray capacitance and the inherent delay through the gate. Adding additional capacitors and a second gate as a buffer makes this circuit both practical and very handy.

This is a good place to jump back into LTspice, which includes Macromodels for simple logic gates in the download bundle.

Bad Macromodels

My first attempts didn't work at all, and to make a long story short, the LTC supplied digital-gate Macromodels are defective for this task. Luckily, better models are readily available

■ FIGURE 6. Phase shift oscillator breadboard frequency.



■ FIGURE 4. Phase shift oscillator simulation.

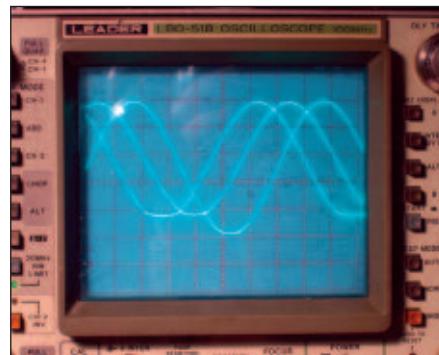
and these are included in the download for this article. If you haven't added Macromodels to your LTspice library yet, refer back to the sidebar, "Adding New Macromodels to LTspice", in last month's installment.

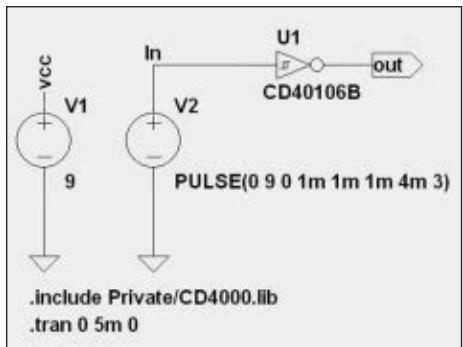
Testing Logic Gates

A good way to see if a logic gate Macromodel is "only digital" (and therefore not useful for oscillators) is to drive it with a ramp waveform (as shown in Figure 8) and the downloaded file NV_SPICE_32.asc. Digital circuits usually don't like slow rise pulses applied to the inputs with the exception of the Schmitt-Trigger types which have better defined upper and lower logic level thresholds than ordinary gates, and internal positive feedback to speed up the output's edges.

In LTspice, we can deliberately

■ FIGURE 7. Phase shift oscillator breadboard waveform traces are: Phase 1, Phase2, and Output; Y = 500 mV/div, X = 50 US/div.

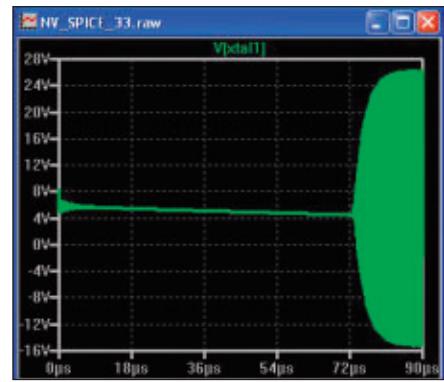




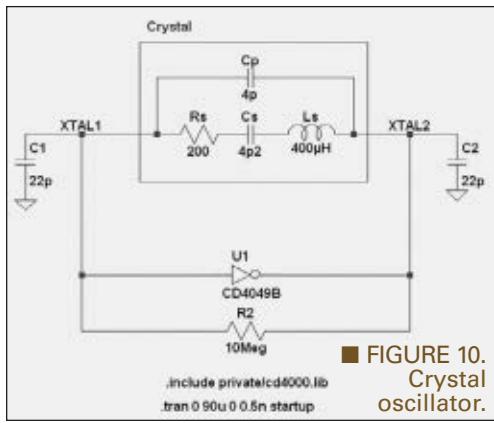
■ FIGURE 8. Logic gate test circuit.



■ FIGURE 9. Logic gate test circuit simulation.



■ FIGURE 11. Crystal oscillator simulation at start-up.



■ FIGURE 10. Crystal oscillator.

drive a logic gate Macromodel with a slow ramp and plot the input and output, as shown in Figure 9.

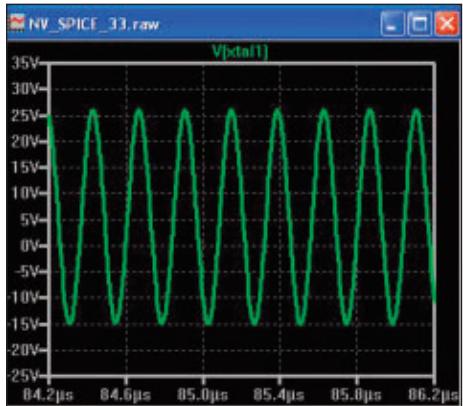
Crystal Oscillators

A crystal controlled oscillator has very good accuracy and stability because it uses a mechanical filter fabricated from a precision ground "slab" of quartz. We're familiar with miniature crystals found in computer hardware — most of which are in the several MHz range. By the way, a

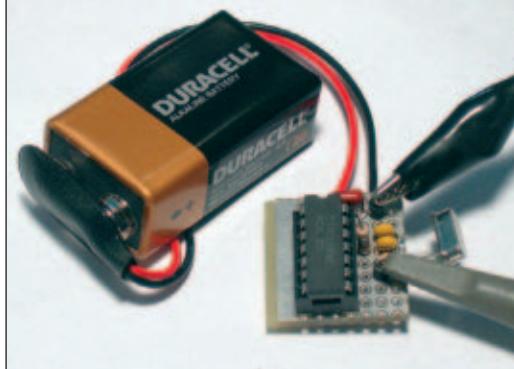
watch crystal has a quartz tuning fork design, is very small, and operates accurately at 32.786 kHz (a number that can be divided down to exactly 1 pps — *one pulse per second* — with 15 binary counter stages in a chain).

Crystal elements only require an external capacitance of a few picofarads for correct frequency operation, typically 10 pF total (two external 22 pF capacitors will do). We can simulate the crystal in LTspice, using L and C elements to represent the mechanical 'slab.' Recall that crystals make stable oscillators due to their very high Q factor (20K-50K) which is expressed as X_L/R , explaining the large inductor and very small capacitor and resistor values in the model. An LTspice crystal model for the crystal oscillator built around a CMOS inverter gate is shown in Figure 10 and the simulation is in Figure 11. Notice that the output doesn't start immediately as the circuit relies on random noise in the amplifier (our digital gate).

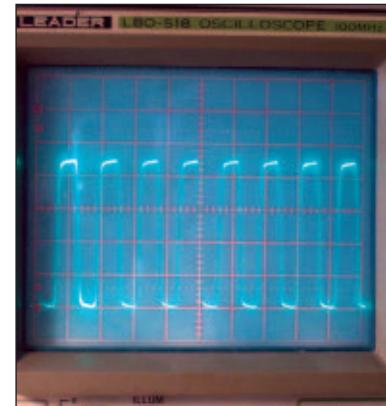
■ FIGURE 12. Crystal oscillator simulation when running.



■ FIGURE 13. Crystal oscillator breadboard.



■ FIGURE 14. Crystal oscillator breadboard waveforms; Y = 2V/div, X = 200 ns/div.



■ FIGURE 15. Unadjusted crystal oscillator breadboard frequency.

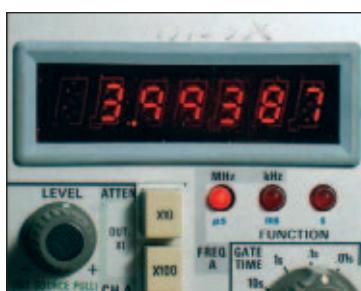
run; it bears the value "Cx." By right-clicking on it, you can set the values for C_p , C_s , L_s , and R_s as shown in Figure 16. And yes, it does exactly what you'd expect when used in the earlier circuit of Figure 10.

I have placed a simulation circuit in the download for this session (NV_SPICE_37) setting up LTspice to sweep the crystal with a virtual VFO (variable frequency oscillator). You can also do this on the bench if you have a suitable VFO and an RF millivoltmeter or oscilloscope, and a frequency counter. This is a handy way to identify any unmarked crystal units.

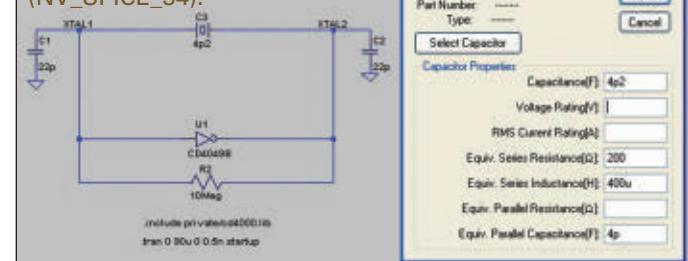
LTspice Units

You may have noticed that I've been sloppy with entering component values into the LTspice diagrams. I did this deliberately as LTspice can accept and understand just about any value units. For example, a resistor of 10K can be entered as 10,000 or 10000 or 10K or even 0.01 Meg.

I like to use the EU format, so a four point, seven kilo-ohm resistor would be written as 4K7, and a four point, seven ohms one as 4R7. If you prefer, you can enter explicit values, or scientific notation too ('0.001' or '1e-3' or '1m' or '1m0' or even '0k000001' are all the same to LTspice). I did trip myself when entering lowercase 'm' when I wanted uppercase 'M.' So, for megohms use Meg!



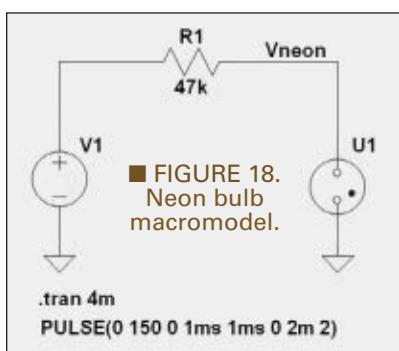
■ FIGURE 16. Crystal oscillator symbol and dialog box (NV_SPICE_34).



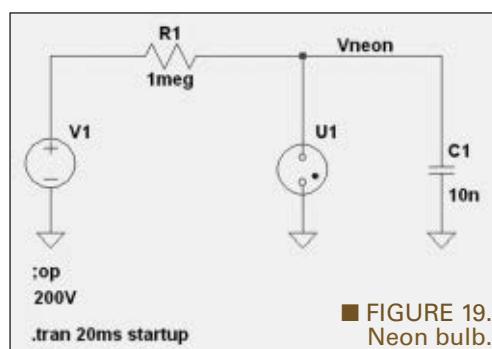
The Hollow State Oscillator (using a neon bulb)

Before the dawn of solid-state electronics, vacuum tubes (or valves) ruled the day. These are sometimes called 'hollow state' or 'glass FETs,' and can be simulated in LTspice. If you're an audiophile or just curious about forgotten technology, then simulation tools come to the rescue. In keeping with our theme of simulating oscillators in this session, I've cooked up a very simple hollow state neon bulb oscillator, with just one capacitor and one resistor.

Recall that a neon bulb has two stable states: off and on (glowing). Applying a low voltage causes little or no current to flow until a threshold is reached around 100V DC. Once the device breaks down and conducts, it has a much lower holding voltage — around 50V — and almost unlimited current. If the current was not limited by an external resistor, the neon bulb would self-destruct! LTspice has a nice neon bulb Macromodel, and we can plot the two stable states by driving it with a linear ramp through a current limiting resistor, as shown in Figure 17 and Figure 18 (run NV_SPICE_34 from the download).



■ FIGURE 18. Neon bulb macromodel.



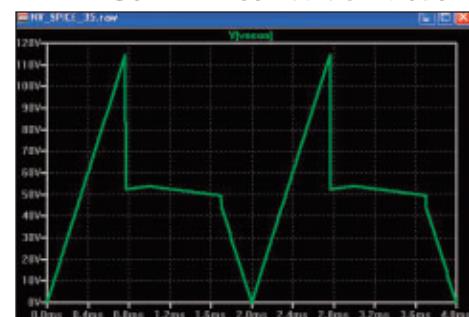
■ FIGURE 19. Neon bulb.

Placing a capacitor across the neon makes a relaxation oscillator, as shown in Figure 19 and Figure 20 (run NV_SPICE_35 from the download).

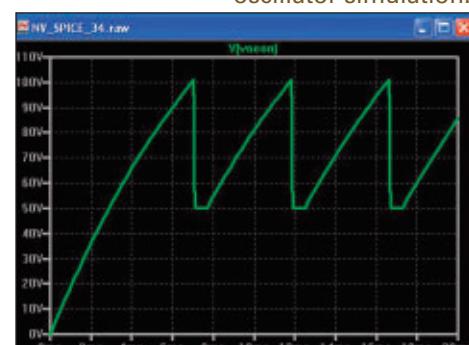
On-Line Support

When I get stuck in LTspice, I turn to a goldmine of knowledge at the LTspice Yahoo Group (<http://tech.groups.yahoo.com/group/LTspice/>). It's a bit intimidating with almost 16,000 members, but so far I've found solid answers and downloaded great Macromodels from the group's files section. If you need a Macromodel for a component, go to that vendor's website and search. All the major semiconductor companies have SPICE model support. NV

■ FIGURE 17. Neon bulb simulation.



■ FIGURE 20. Neon bulb oscillator simulation.



"How To" BASICS

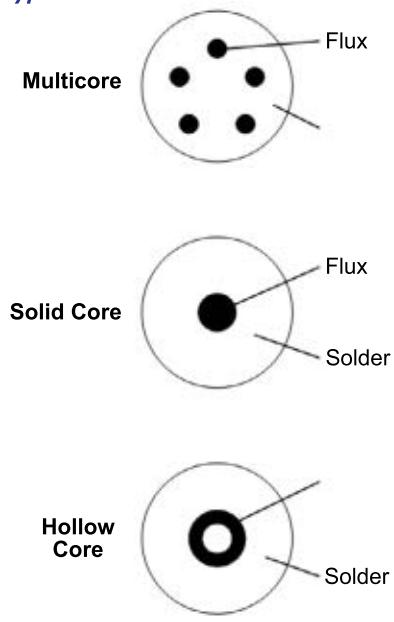
A guide to soldering

BY JAMES L. ANTONAKOS

Finally, electronic components can simply be soldered together. Soldering involves heating up the metal leads of the components and then coating them with a different molten metal. This makes for both good electrical and mechanical connections, that ideally, will not come apart when the leads of the components are moved or vibrated.

A typical solder is an alloy made up of 60% lead and 40% tin; it is thus referred to as 60/40 solder. It comes on a roll in the form of a thin, flexible wire that is pushed into the area being heated to make it melt. Figure 1 shows the cross section of three different types of solder wire, all of which contain some internal resin or flux — a chemical used to clean and wet the metal surfaces.

FIGURE 1. Cross section of three types of solder wire.



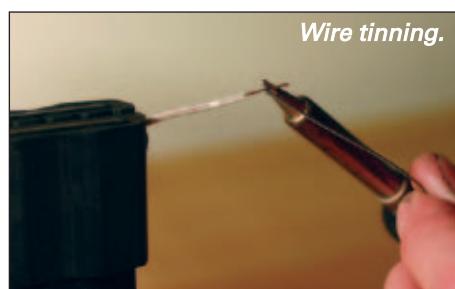
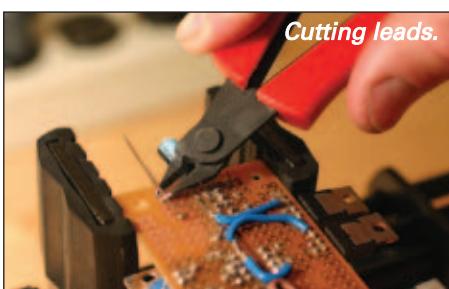
There are many ways to connect electronic components together to form a working circuit. They can be wire-wrapped or their leads can be pushed into small metal springs popular with 100-in-one electronic kits available at RadioShack.

The components can also be placed into small plastic cubes with metal tabs on each side and inserted into a two-dimensional grid to form a circuit, another hobbyist fabrication for fashioning your own electronic projects.

Let's Begin

What do you need to begin soldering? First, you need something to solder. This may be as simple as a few wires that you want to tin or as complex as a radio or other electronic kit that does something interesting. Next, you need a soldering iron, some solder, and a small wet sponge. Figure 2 shows all these items. A soldering iron is essentially an electric heater. The tip of the soldering iron gets very hot. Placing the tip onto the wire leads of two components transfers heat to the leads. When the leads get hot enough, they will melt the solder that is applied to them. When the soldering iron is removed, the molten solder will slowly cool and harden, making a strong, highly conductive connection between the wire leads. As the solder melts, it gives off smoke. Hold your head back so the smoke does not get in your eyes — or lungs — as you work.

The small wet sponge is used to clean the tip of the soldering iron before it is used each time. The high heat of the tip causes it to rapidly oxidize, which reduces its ability to transfer heat. So, before you place the tip



onto the leads you want to solder, you first rub the tip across the wet sponge to clean it. Then, you melt a little solder onto the tip to make it easier to transfer heat to the items being soldered.

You will also need a pair of cutters to trim off the excess leads after you have soldered them. This is necessary whether you are soldering components to a printed circuit board or twisting them together to make a connection. When you clip the leads, wear goggles to protect your eyes as the leads sometimes fly away very quickly when cut. You may want to point the lead being clipped down directly into a wastebasket while clipping it, both to protect your eyes and to catch the clipped lead.

You should wear long pants while soldering. Since you are almost always sitting while soldering, it is not uncommon for molten solder to accidentally drip off the tip of the soldering iron when you pull it away from the circuit. Sometimes the molten solder drips onto the table where you are working, but it could drip onto your legs. It is very hot and will easily burn you if it falls on your bare skin.

Soldering To A PCB

If you are soldering components to a printed circuit board (PCB), it is important that the copper traces on it are clean. Copper will slowly oxidize when exposed to air (actually, the pollutants that are in air). This thin layer of oxidation will make it harder for the solder to adhere to the copper. It is a good idea to gently rub the traces with steel wool or fine sandpaper before soldering anything to them. This removes the layer of oxidation and makes tiny scratches in the copper, which also increases its surface area and gives the solder more places to attach. After you have cleaned the traces, be sure not to touch them with your fingers. Hold the PCB by its edges as the oil on your fingers will deposit on the copper and begin oxidizing it. If you wait long enough, you will eventually see the pattern of your fingerprint etched in the copper!

It is usually necessary to solder wires to a PCB to carry power to the board and signals to the off-board

FIGURE 2. Here is everything you need to solder an electronic project.

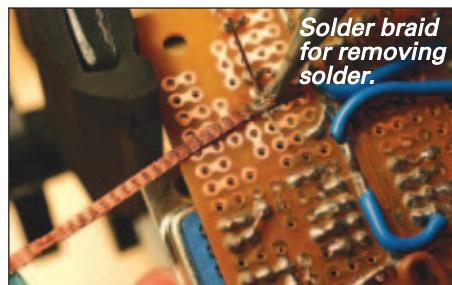
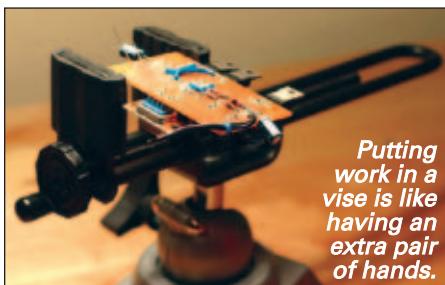


components such as switches and speakers. If the wire is stranded, you may want to tin the wire before soldering it to the board. Tinning places a small coating of solder over the wire and makes it easier to work with and solder to the circuit board. It also makes the wire stronger and able to put up with some bending without individual strands breaking off.

How To Tin A Wire

First, the bare stranded wire is twisted to make a tight rigid tube with all the wires going in the same direction. Then, solder is applied to the tip of the soldering iron and the tip applied to the wire. Melt a small amount of solder onto the wire until it is evenly coated. With the wire tinned in this way, it can easily be pushed through a hole in the circuit board, or bent into a shape that it needs to be in, or wrapped around a screw before it is tightened down.

Keeping the PCB or other items you are soldering steady is important. It is very frustrating to try and



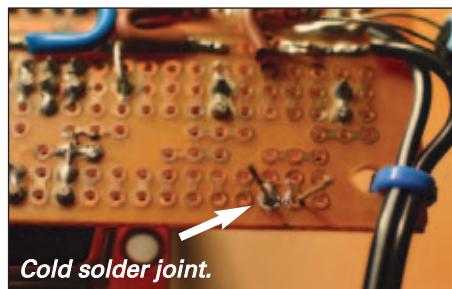
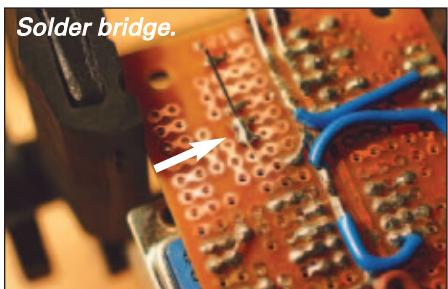
solder with the board or wires moving all over the place. It may be necessary to use a small vise or other gripping tool to hold the board or wires steady while you solder.

Care Is Required

There are a few problems to watch out for while soldering. First, you may accidentally create a solder bridge. This is a blob of solder that fills the gaps between two different soldered connections. For example, on a PCB the copper pads where component leads are soldered are sometimes very close to each other. If too much solder is applied to one copper pad, it may overflow and spill over to another pad. The solder has now made an electrical connection between the two copper pads. This connection is called a solder bridge. Unfortunately, this connection is not intended and changes the circuit. The change may prevent the circuit from working, create a short that blows a fuse when you apply power, or have some other negative effect on the circuit's operation. For these reasons, the solder bridge must be removed. This is accomplished by reheating the solder that forms the bridge using the tip of the soldering iron. Sometimes you can use the tip to gently push the solder around enough to break the bridge. Solder — like water and other liquids — has surface tension when it is molten and will naturally try to bead together. If there is too much solder in the bridge, this method will not work and you will have to remove some of it. This can be done using a solder braid to absorb the extra solder. A solder braid is a stringy copper mesh that is heated and placed onto a blob of solder. When the solder melts, it transfers to the braid, coating it and filling the gaps in the mesh.

Another way to remove a solder bridge is to heat up the solder to make it melt and then suck it up with a solder sucker. This is a small handheld tool that uses a vacuum to pull the molten solder away from a copper pad or other connection.

It is important to understand that the solder is not melted by the soldering iron tip and then dripped onto the items being soldered. The solder must be melted by the heat of the items being soldered. Otherwise, you may encounter another problem called a cold solder joint. In this situation, the solder has cooled too quickly and becomes brittle. The solder may actually crumble



Contact the Author

You can reach James Antonakos at antonakos_j@sunnybrook.edu or visit his website at www.sunnybrook.edu/~antonakos_j.

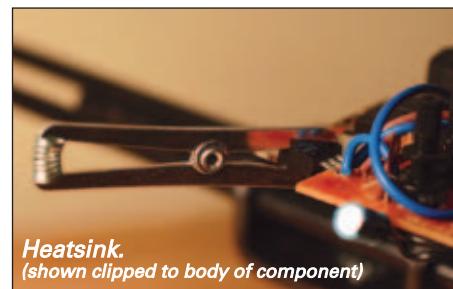
when it is wiggled. A cold solder joint typically makes a poor connection, as well. This may manifest itself as an intermittent problem that shows up and goes away in your circuit, especially when the circuit is moved. Unlike the bright, shiny, smooth surface of a proper solder connection, the cold solder joint looks flat and pitted. It is not difficult to make a cold solder joint. Simply blowing on the molten solder makes it cool quicker. It is best to let the solder cool on its own.

Protect Your Components!

Sometimes the component whose leads are being soldered is sensitive to heat. In order to protect it, a heatsink is used. The heatsink connects to the lead being soldered, gripping it tightly. If one is not available, an easy substitute is to take a pair of needle-nose pliers and wrap a rubber band around the handles. The rubber band will try to keep the pliers closed. Then, the pliers are used to grab the lead of the component being soldered. The better the grip the pliers have on the component lead, the more heat they will transfer away from it.

When you have finished using the soldering iron, it should be unplugged and allowed to cool before it is put away. While it is still hot, it is a good idea to clean the tip a final time with the wet sponge.

If you have never soldered before, how do you get started? A trip to RadioShack or some time spent in an electronics magazine (such as *Nuts & Volts*) will present you with an opportunity to buy a soldering iron kit complete with sponge and solder. And again, you also need something to solder. Buy an electronic project kit. Start small with a simple circuit that only has a few components, such as an LED flasher or a music board with a single integrated circuit. Build up your confidence by completing the simple circuit and getting the satisfaction of seeing it work when you turn it on. If it does not work, look for unsoldered leads, solder bridges, or components inserted incorrectly. **NV**



ELECTRO **NET**

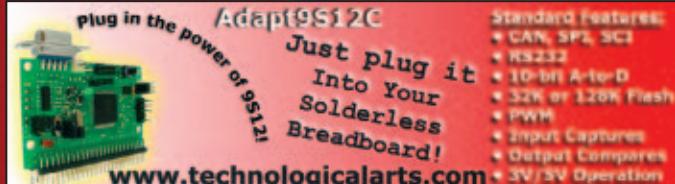
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■ BY FRED EADY

A REASONABLE REPLACEMENT FOR RS-232

I'VE FINALLY BEEN PUSHED OVER THE EDGE. I'm going to include USB interfaces on subsequent Design Cycle projects that require serial communications with a personal computer. This has been a long time coming as I have been purposely steering clear of anything USB in our Design Cycle projects. My gun-shy attitude towards USB is rooted in my past experiences with attempting to understand and apply USB technology to my embedded designs. I recall trying to understand all of the tables and states that the USB protocol required for proper operation, and the tremendous coding effort that, at the time, was necessary to build a USB interface. All of that stuff turned me off to using USB in my projects.

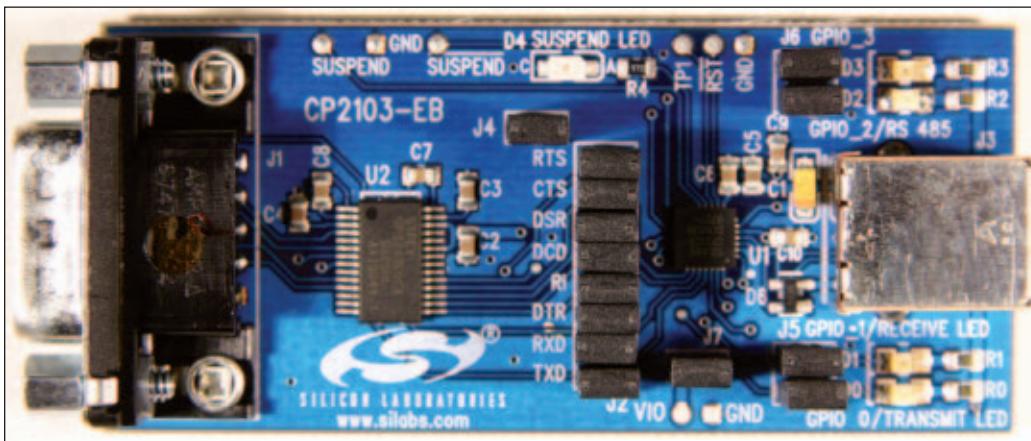
I've been peeking through the fence at stand-alone USB ICs that are capable of replacing the venerable RS-232 interface ICs I've grown to love over the years. The new generation of USB ICs claim to be able to fall into the place of legacy RS-232 drivers with nothing more than a printed circuit board (PCB) change. That's fine on the hardware side. However, what really has to be done on the firmware side to make the transition? Is the transition to the USB firmware interface driver a "no-brainer," as well?

THE SILICON LABORATORIES CP2103

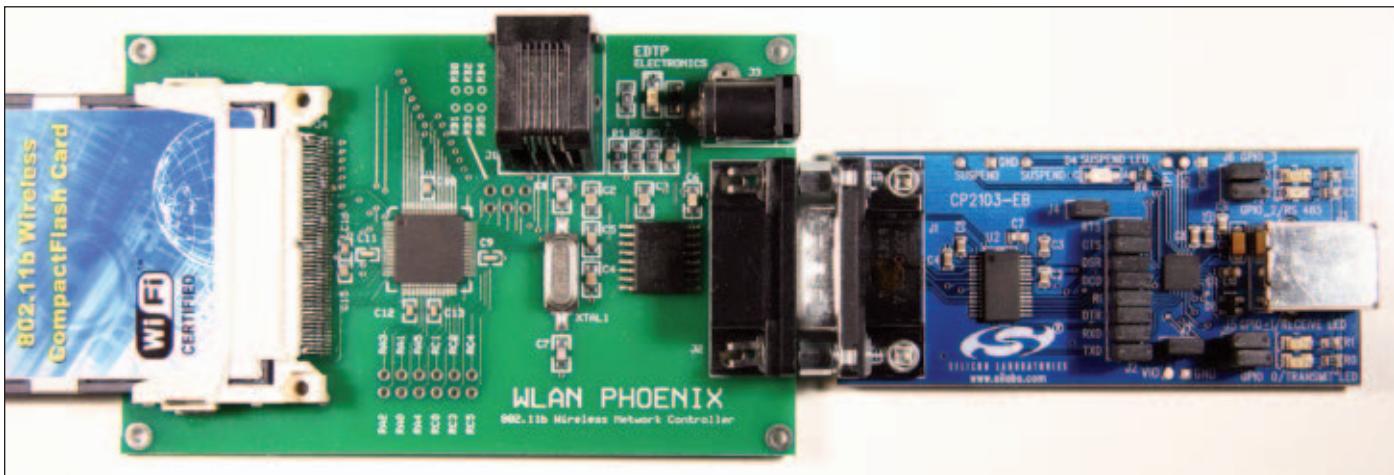
The majority of the microcontroller projects I do for Design Cycle include an RS-232 interface in the design.

The advantages of implementing a microcontroller RS-232 interface are many. For instance, a microcontroller equipped with an internal UART can easily transfer data between itself and another microcontroller, or itself and a PC application. A microcontroller RS-232 interface is also an easy way to provide visual indicators for human consumption. A good example of a microcontroller application using its RS-232 interface to convey information to a human via a PC terminal emulator application is the WLAN Phoenix. Not only does the Phoenix microcontroller application display IP and MAC addresses, the embedded RS-232 interface allows the personal PC emulator application to pass human-generated information from the PC to the microcontroller.

According to the CP2103 datasheet, using it to replace the RS-232



■ PHOTO 1. Most of the Evaluation Kit printed circuit board is dedicated to allowing the user access to the CP2103's hardware resources. The SP3243EU RS-232 converter IC is included to allow easy connection to a device equipped with a standard RS-232 interface. The USB side of the Evaluation Kit is intended to connect to a personal computer.



hardware will allow us to perform the same tasks we just discussed using a drop-in USB interface.

The CP2103 is designed to transition a piece of hardware from an RS-232/485 interface to a USB interface. I was attracted to the CP2103 because of its skinny schematic diagram. If I believe what the CP2103 datasheet schematic is telling me, it doesn't require any external resistors or crystals to bring a fully compliant USB 2.0 interface to life. The silicon encapsulates a level 2.0 full-speed function controller, transceiver, EEPROM, oscillator, and UART in a tiny QFN-28 package. The internal EEPROM is used for storing vendor-specific information in commercial applications. If we find that we need to access the EEPROM, there is easy access and programming via its USB interface.

Silicon Laboratories has taken care of the PC side of things by supplying royalty-free Virtual COM Port (VCP) device drivers. If you've ever used a PC RS-232-to-USB converter, you know that it looks like a standard COM port to the PC and its applications. The VCP device driver also pretends to be a standard COM port. That means that we can use our newly acquired microcontroller USB interface to communicate with a Tera Term Pro terminal window on a computer just as if we were using RS-232 hardware on the embedded side.

In many of the projects we've done in Design Cycle, industry standard regulated power supply circuitry was eliminated and replaced by regulated wall warts. Including the CP2103 in our future designs will allow us to totally eliminate the wall warts, as well. As long as our embedded microcontroller designs don't draw more than 500 mA of current, we can power them directly from the USB connection. The CP2103 can also

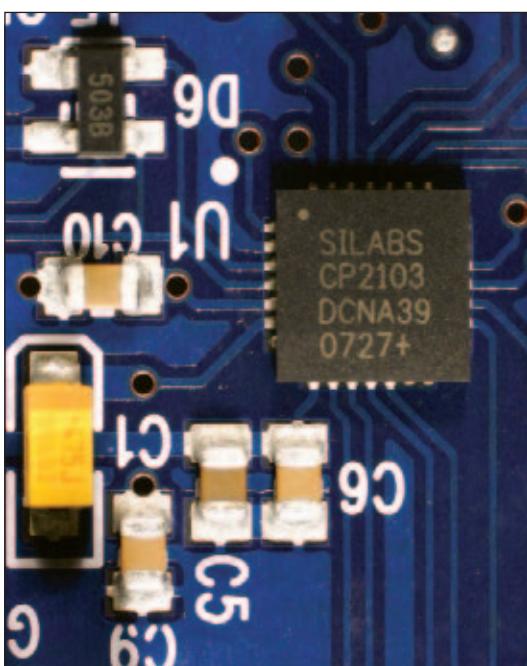
■ PHOTO 2. This is the long way around as the WLAN Phoenix has its own SP3232 RS-232 converter IC. The idea is to use a CP2103 to get rid of both of the RS-232 converters in this shot.

accommodate a 3.3 volt microcontroller system as its on-chip 3.3 VDC voltage regulator can supply up to 100 mA to external circuitry.

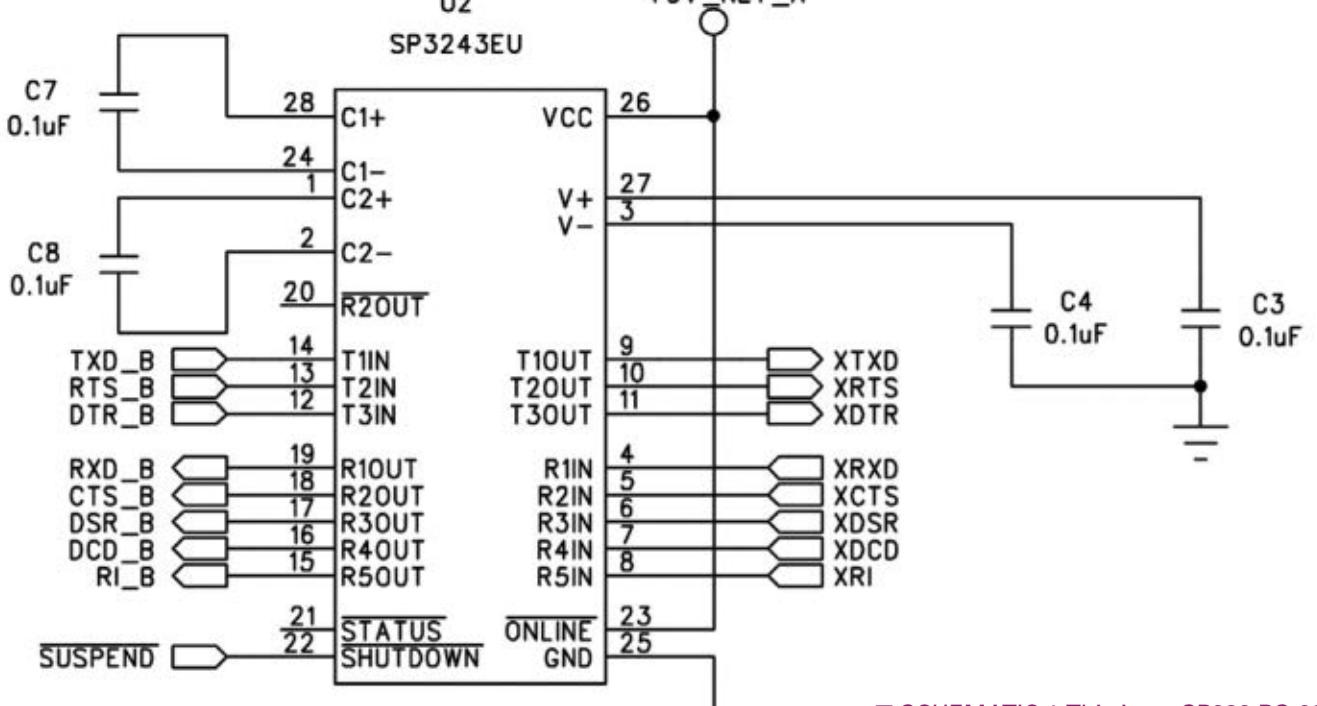
Let's talk about the functional blocks that make up the CP2103 beginning with the USB function controller and transceiver. Basically, the USB function controller manages all of the data transfers between the UART and USB interfaces. The USB function controller is also responsible for handling command requests that are generated by the USB host controller. The CP2103's internal UART is also under the command of the USB function controller. The CP2103's USB 2.0-compliant transceiver's functionality is rather obvious. The transceiver's only reason to live is to send and receive serial data on the USB bus.

There's nothing remarkable about the CP2103's UART interface. If you think about all that has been said about how the CP2103 can replace an SP233ACP, it would make sense that the UART does everything exactly like any other UART would. But in fact, it is much more sophisticated than what is found on many UART-equipped microcontrollers. In addition to the standard TXD and RXD (transmit and receive) signals, the CP2103's UART interface includes all of the standard EIA modem signals.

For those of you that are too young to remember dial-up BBSs and watching modem LEDs blinking late into the night, the



■ PHOTO 3. Only seven inexpensive components and a USB connector are needed to put a CP2103-based USB interface to work. These components are mounted on the CP2103 Evaluation Kit printed circuit board.



■ SCHEMATIC 1. This is an SP232 RS-232 converter IC on steroids. The active low SUSPEND line is used to conserve power when the CP2103 goes into SUSPEND mode.

standard EIA modem signals include:

- RTS - Request To Send
- CTS - Clear To Send
- DSR - Data Set Ready
- DTR - Data Terminal Ready
- DCD - Data Carrier Detect
- RI - Ring Indicate

The DTR and RTS modem signals are generated by the DTE, or Data Terminal Equipment. Your PC qualifies as a DTE device. Under normal circumstances, the modem – or Data Communications Equipment (DCE) – responds to a DTR signal with a DSR signal which indicates that the modem is powered up and can communicate with the DTE. The DTE device raises the RTS signal to the modem when it wants to transmit. If the coast is clear, the modem responds to the DTE device by raising the CTS signal. When a remote modem is contacted and the carrier is sensed, the DCD line is asserted, telling the DTE that a link has been established. For switched (dial-up) links, the modem raises RI when the phone line it is attached to is ringing. The RI signal is used by the software for unsophisticated modems that cannot auto answer.

Every conceivable baud rate from 300 to 921600 bps is supported by the CP2103's UART interface, which can also speak all of the parity, data bit, and stop bit combinations.

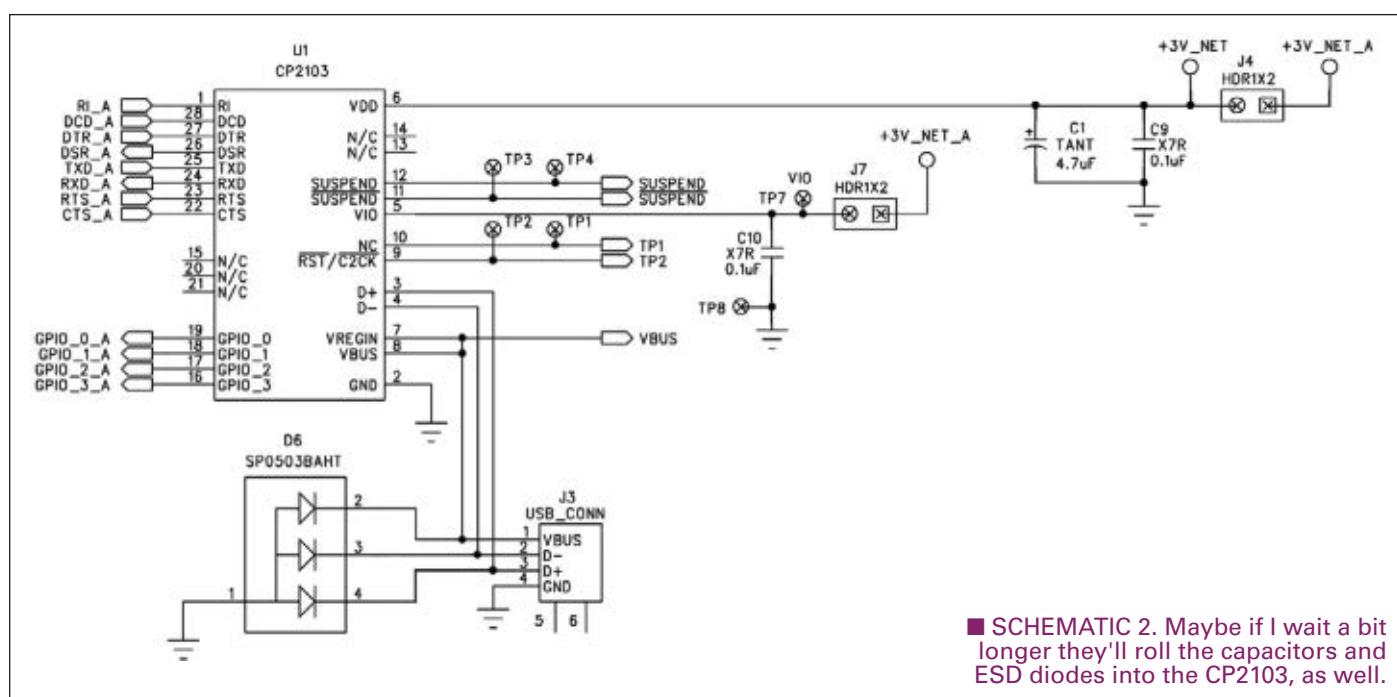
One of my concerns about moving to a USB interface involves the customization of each USB equipped device.

Once again, the engineers at Silicon Laboratories have provided an out in the customization maze. As long as we stick with their USB ICs, we can use the free Product ID (PID) provided by Silicon Laboratories in conjunction with their Vendor ID (VID). Using Silicon's PID and VID with a unique serial number will assure the uniqueness of each USB device sporting a CP2103. All of the customization we just discussed is written to the CP2103's internal EEPROM. Yep, Silicon Laboratories provides the stand-alone EEPROM programming utility we will need to perform the customization.

This drop-in-no-software-modification USB wonder IC sounds too good to be true. However, before we commit anything CP2103 to a Design Cycle project PCB, we'll take a complete tour of the Eval Kit's hardware and software. If adding USB capability to a microcontroller is as easy as the datasheet says it is, we'll exercise some PIC test hardware along the way.

THE CP2103 EVALUATION KIT

The Evaluation Kit PCB is laid out in such a way as to allow us to easily tap into the CP2103's resources. The user-accessible tap points can be found under every jumper block you see in Photo 1. The jumpers connect the CP2103 to the SP3243EU RS-232 converter IC and a gaggle of indicator LEDs. As you can see in Schematic 1, a complete RS-232 interface is built around the SP3243EU. The idea is to connect a legacy RS-232 device to the nine-pin end of the Kit which becomes a transparent bridge to a PC's USB port.



■ SCHEMATIC 2. Maybe if I wait a bit longer they'll roll the capacitors and ESD diodes into the CP2103, as well.

With the Eval Kit, we have all of the necessary hardware to make a USB-to-RS-232 connection. However, not one bit of data will transfer without the help of the Virtual COM Port (VCP) driver. The Kit comes with a CD-ROM which contains the VCP drivers, the CP2103 datasheet, a User's Guide, application notes, the USBXpress Development Kit application, and some example software. The USBXpress Development Kit is intended for those of you that wish to roll your own CP2103 based application using Visual C++ or Visual Basic. Some very useful CP2103 configuration utility programs are also part of the USBXpress Development Kit package.

I loaded up the Windows VCP driver without incident. Since our goal is to replace an old-fashioned piece of RS-232 hardware with a new fangled piece of tiny USB hardware in an embedded environment, I decided that a good initial test of the CP2103's capabilities would be to interface a WLAN Phoenix's RS-232 port to the Eval Kit. The Phoenix/CP2103 lashup can be seen in Photo 2. For those of you that are unfamiliar with the Phoenix, it is a PIC18LF6722-based Wi-Fi device that was featured in a previous edition of Design Cycle.

The Phoenix will transmit a menu via its RS-232 port at power-up. If the CP2103 is really a candidate to be a transparent replacement for the SP3232, I should be able to fire up a Tera Term Pro terminal emulation session on my laptop and receive the Phoenix's power-up menu message from its RS-232 port by way of this new USB interface. With that, I proceeded to the Windows Device Manager to force the CP2103's VCP driver to lock into COM1 of my laptop. I then invoked a Tera Term Pro session on the laptop and set the terminal emulator for COM1 operation at 57600 bps, which matches that of the Phoenix's serial port. I powered up the Phoenix and behold! The menu you see in Screenshot 1 appeared in

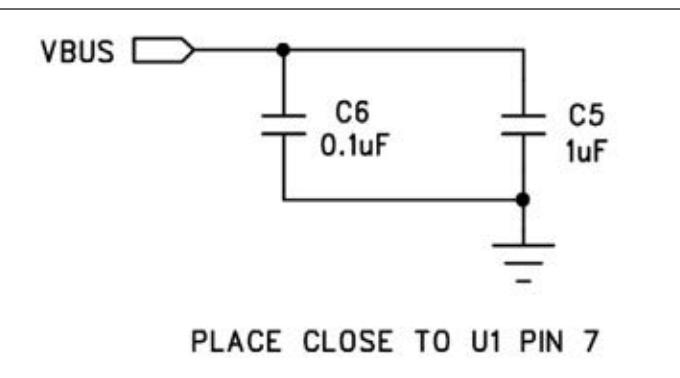
the laptop's Tera Term Pro emulator window. I've seen enough. Let's lay the groundwork towards building up some project hardware that incorporates the CP2103.

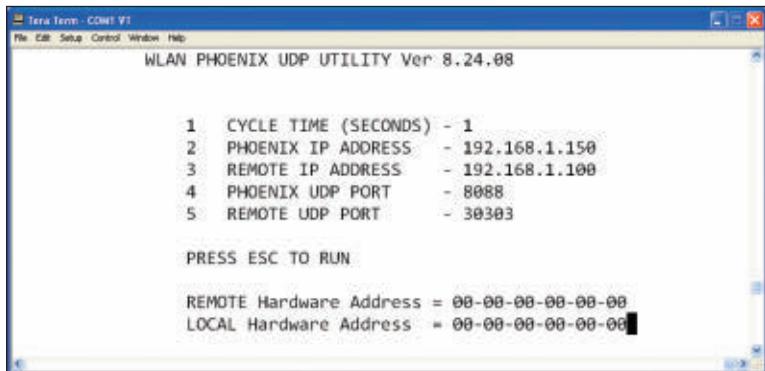
DESIGNING WITH THE CP2103

If you take a count of the actual electronic components in Schematic 2, you can total them all on the fingers of one hand. Let's see if we can figure out what those five components are doing for us. All of the CP2103 pins on the left-hand side of the schematic are dedicated to the RS-232 interface with the exception of the CP2103's GPIO pins, which we're going to ignore for now. The datasheet tells us that all of the modem control signal pins can be left disconnected if not used. Only the TXD and RXD signal pins are excluded from optional disconnection. So, let's begin with pin 6 of the CP2103 and work our way down the right-hand side of Schematic 2.

Pin 6 V_{DD} of the CP2103 is interesting as it appears that this pin can either supply power or receive it. The

■ SCHEMATIC 3. Adding a couple of inexpensive parts is a small price to pay for circuit stability.





■ **SCREENSHOT 1.** Upon power-up, this is the menu that greets WLAN Phoenix users. This message bounced through an SP3232 on the WLAN Phoenix to the SP3243EU on the CP2103 Evaluation Kit board and out of the CP2103 USB interface to the Tera Term Pro terminal emulator application running on my laptop.

CP2103 has its own five volt to three volt voltage regulator. The CP2103's on-chip voltage regulator allows the CP2103 to use the USB bus power or be powered by an external power source. In USBese, powered by an external source is termed self-powered.

There are three configurations in which the CP2103's V_{DD} pin can participate. In USB Bus-Powered mode, the V_{DD} pin is internally connected to the CP2103's internal voltage regulator output. The CP2103's VBUS and REGIN (CP2103 voltage regulator input) pins are both tied to the incoming VBUS source in USB Bus-Powered mode. The USB Bus-Powered configuration enables the CP2103's voltage regulator output to be used to power external circuitry. With 100 mA of available current capacity, the CP2103's internal three-volt voltage regulator can easily power a typical PIC microcontroller. If you examine Schematic 2, you'll see that the CP2103 Evaluation Kit is configured as a USB Bus-Powered device. The 4.7 μ F tantalum capacitor hanging on the V_{DD} pin is recommended when the CP2103's internal voltage regulator is servicing devices in addition to the CP2103 itself. The additional 0.1 μ F capacitor attached between the V_{DD} pin and ground is for noise suppression. USB Self-Powered mode is in effect when an external five volt power source is connected to the CP2103's REGIN pin. The VBUS source is also connected to the VBUS sense input pin and the internal voltage regulator is enabled, providing three volts on the V_{DD} pin for possible use by supporting circuitry.

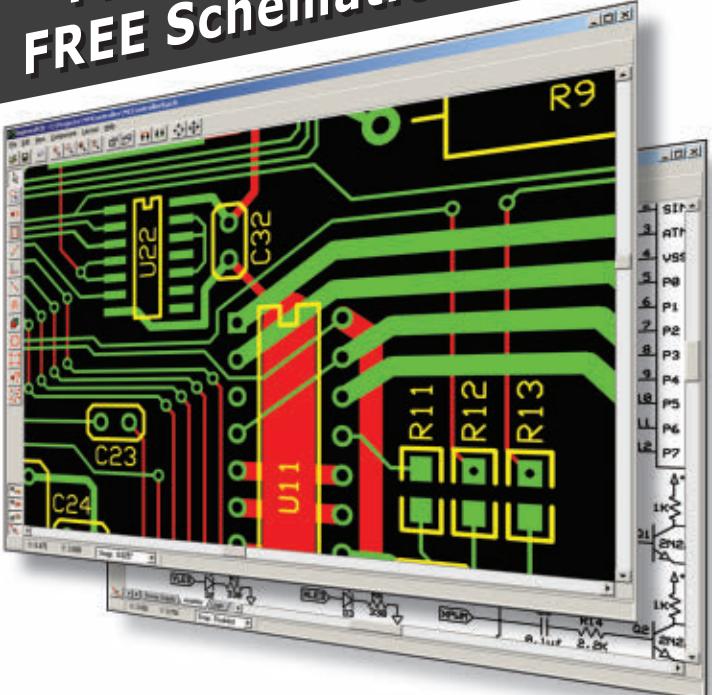
If 3V is applied to the V_{DD} and REGIN pins, the internal voltage regulator is disabled and the CP2103 is considered a USB self-powered device. The VBUS sense input is fed by the VBUS source in the configuration, which is defined as USB Self-Powered, Regulator Bypassed mode.

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Pins 11 and 12 are used for power management. The CP2103's USB function controller supports USB Suspend and Resume signals, and extends the USB power management functionality to external devices via the active high SUSPEND and active low /SUSPEND pins. The CP2103 enters Suspend mode when a suspend signal is active on the bus. An example of how the SUSPEND signals are used can be seen in Schematic 1. Note that the SP3243EU's /SHUTDOWN pin is under the control of the /SUSPEND pin. When the CP2103 goes into Suspend mode, it also shuts down the SP3243EU. The CP2103 exits Suspend mode upon receiving Resume signaling on the bus. A USB Reset signal or a device reset will also terminate Suspend mode.

VBUS, D+, and D- are standard USB signals. The SP0503BAHT attached to these signals is a trio of avalanche transient voltage suppression diodes that are used here for ESD (Electrostatic Discharge) protection.

Driving the CP2103's /RST pin low for more than 15 µs will initiate a CP2103 system reset. The /RST pin is open drain and reflects the status of a CP2103 internal power on reset.

The CP2103's V_{I0} pin is a power input pin that determines the voltage level support for the I/O pins. Voltage at the V_{I0} pin can vary between 1.8 volts and V_{DD}. A 0.1 µF bypass capacitor is present on the V_{I0} pin to suppress noise.

The only remaining components we need to consider in a CP2103 design are shown in Schematic 3. Adding these VBUS bypass capacitors brings the total CP2103 system parts count to seven. It's really sobering to realize that the seeming expanse of the schematics is all contained in the macro view of the CP2103 and its supporting components you see in Photo 3.

BUILD IT FEVER

I'm really anxious to lay out the

SOURCES

Silicon Laboratories
www.silabs.com

CP2103; CP2103 Evaluation Kit

EDTP Electronics, Inc.
www.edtp.com
WLAN Phoenix

ExpressPCB pads and traces for the CP2103 hardware project. Now that we have some idea of what it's going to take to put a CP2103 USB interface together, I'll come up with a CP2103/microcontroller hardware design and have it ready for the next installment of Design Cycle. We'll also take a closer look at USBXpress and use its utilities to customize our CP2103. So, polish up your soldering equipment as you're going to need it. We're about to add USB to your Design Cycle. **NV**

■ Fred Eady can be contacted via email at fred@edtp.com

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SMILEY'S WORKSHOP

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by Joe Pardue

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webstore at www.nutsvolts.com

Last month, we learned about both of those binary 10 kinds of people. This month, we will apply it to understanding Binary Coded Decimal (BCD) to use in code for a wearable Butterfly Alarm Clock (see the safety pin shown in Figure 2). We will also discuss functions and variables and learn that 'automatic' variables can only be used in the function where they are declared but 'external' variables — declared outside any function — can be used anywhere in the software module.

Function Basics

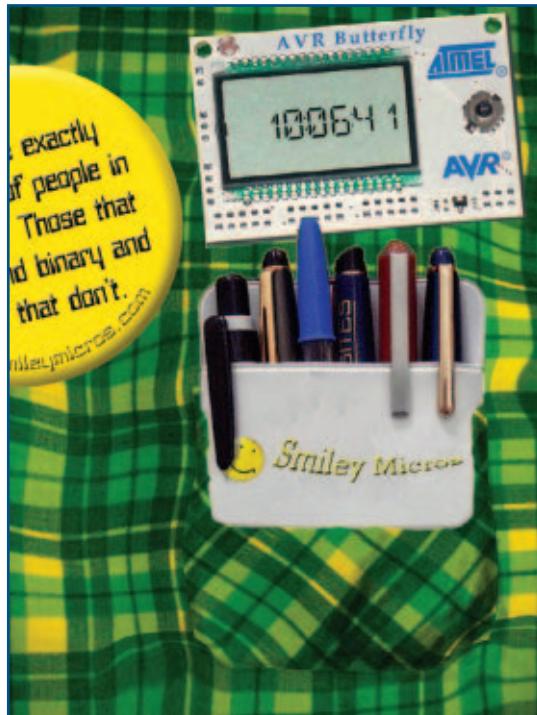
We've been using functions for a while, so you should have a feel for them. But let's go ahead and take a more detailed look.

Functions encapsulate a computation. Think of them as building material for C programs.

A house is built of studs, nails, and panels. The architect is assured that all 2x4 studs are the same, as are each of the nails and the panels, so there is no need to worry about how to make a 2x4 or a nail or a panel — you just stick them where needed. Likewise, a function can be considered a standard component for building software. It will always do whatever it does and you don't have to worry about how it does it.

Encapsulation is a key idea in programming and provides the possibility of making chunks of code convenient to use. And just as important, it provides a way to make tested code reusable while not allowing the programmer to mess with it and chance breaking something. We saw some of this in our earlier introduction to libraries.

Functions also help clarify code. A function should do only one thing. If you find yourself writing a function that seems to be doing two separable things, try separating it into two functions for clarity.



■ FIGURE 1. World's Geekiest Shirt Contest.

A function must be **declared** or **defined** in a module (a single text file of code) — usually in a header file or before the main() function — before it is encountered by the compiler.

In Workshop 4, you saw a function declaration in smws4.h:

```
uint8_t receiveByte(void);
```

This told the compiler that we would be using a function named receiveByte that takes no parameters (void) and returns a byte; that to prevent confusion, we call uint8_t (a standard data type for avrlibc). Okay, this seems like a mighty confusing way to prevent confusion, but in regular old-fashioned C we would call a byte an 'unsigned char,' however, there is no guarantee what size a char is, and having an unsigned character doesn't make a lot of sense anyway. What would a

character '-A' be? So anyway, we use the uint8_t telling us that our data type is an unsigned integer made of eight bits and God only knows what the '_t' is there for other than to make typing harder.

Functions can have parameters — a list of variables that may be used by the function — such as a1 and a2 in:

```
uint8_t adder(uint8_t a1, uint8_t a2)
```

They can return values, such as a uint8_t in the adder() function.

One thing that often confuses folks about function parameters is that the function only sees a copy of the parameter, not the original variable. The confusion comes when one thinks that by changing the received parameter in the function body that on return, the caller will see that parameter changed. It won't.

Let's look at a bad function: adder() that has three parameters — adds the first two and puts the results

into the third parameter:

```
// bad function
void adder(uint8_t a1, uint8_t a2,
           uint8_t results)
{
    results = a1 + a2;
}
```

Let's call it with:

```
adderTest()
{
    uint8_t add1 = 1;
    uint8_t add2 = 1;
    uint8_t results = 0;

    adder(add1,add2,results);

    if(results == 2) getRewarded();
    else getBoinked();
}
```

If you think $1 + 1 = 2$ in this example, then prepare to get boinked. In the adder function, 'results' = 2, but this doesn't change anything in the parameter list in the adderTest() function that called the adder() function.

Returns

Ouch! Boinking hurts, so let's make adder work right. We change the return type from void to uint8_t:

```
// good function
uint8_t adder(uint8_t a1, uint8_t a2)
{
    uint8_t results;

    results = a1 + a2;
    return (results);
}
```

Now you will get rewarded. (And we have a useless function. If we want to add 1 and 1, we just use the + operator to add them, but you get the point.)

Automatic And External Variables

Another way to do the adder() thing would be to use an **external** variable (**global**). These are variables defined outside any function, usually in a header or before main(), and are available for any function to use. We contrast external variable to **automatic** variable, such as the uint8_t results declared in the above adder() function. This variable is created 'automatically' every time the function is called and disappears when the function is exited.

Using external variables, we could write:

```
// define the function
void adder(uint8_t, uint8_t);

// create an external variable
uint8_t results = 0;
```

```
int main()
{
    unsigned char add1 = 1;
    unsigned char add2 = 1;

    adder(add1,add2);

    if(results == 2) getRewarded();
    else getBoinked();
}

// This works because 'results' is external
void adder(unsigned char a1, unsigned char a2)
{
    results = a1 + a2;
}
```

This would work fine, unless an interrupt triggered right after we set results in adder() and changed external variable 'results' to 3. Then, when the interrupt finishes and we look at results in main() we get boinked again.

Be very careful using external variables. You never know where they've been or what kind of nasty stuff they might track in. And, unlike automatic variables, they permanently occupy memory. Carefully used however (as in our wearable clock), they are just fine.

Variable names have **scope**, meaning the sections of code where they are recognized that determine how they can be used. External variables can be used by anything in the module, but variables defined within a function can only be used by that function.

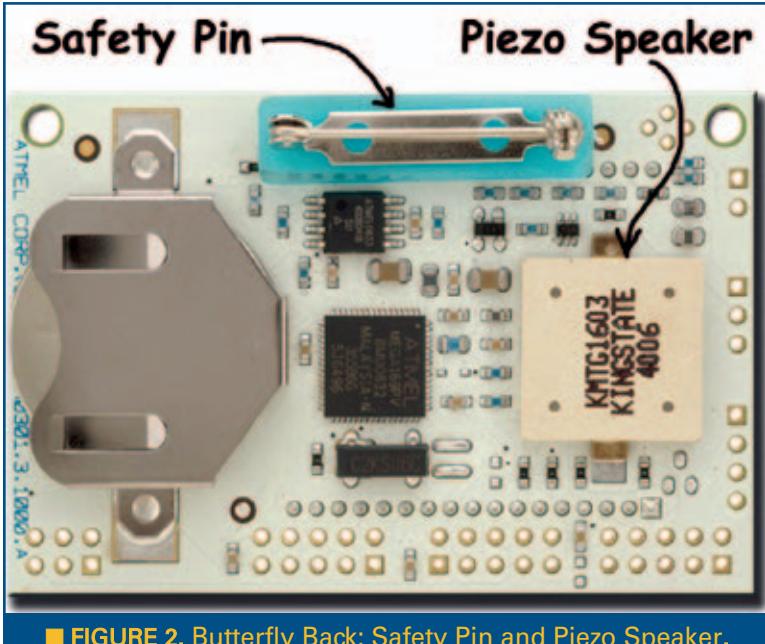
Volatile

We can add the qualifier '**volatile**' to a variable name to tell the compiler to leave it alone when it is optimizing the code (it's complicated and compiler-dependent). Usually, we only need to do this when the variable will be changed by an interrupt as in our clock code. Newbies using interrupts often forget about volatile and have mysterious difficulties to finding bugs as a result.

Due to space limitations, we will put some additional C syntax and compiler topics into a downloadable supplement listed at the end of this article.

Computer Time Keeping

Computers are made of electric circuits that rely on one sequence of events completing before the next sequence of events can be looked at (sequential state machines). Changes in voltages and currents take time to stabilize so for each change in the state of the microcontroller, it must wait a bit of time to let things settle down before allowing states to change again. The quickest that the computer circuits can settle determines the fastest speed the computer can run. The datasheets provide this value, for instance, some AVRs have a maximum frequency of 20 MHz, meaning that they will run reliably at that speed. They might run just fine at 25 MHz, but Atmel won't guarantee it and it is kind of



■ FIGURE 2. Butterfly Back: Safety Pin and Piezo Speaker.

foolish to try to 'overclock' a computer, it might seem to run perfectly until a critical event and run off crazy and raise the landing gear moments before touchdown.

Also, the faster you run a CPU, the more power it uses. The Butterfly uses an ATmega169 that can run at 8 MHz, but what's the hurry? Many AVRs can run off an internal oscillator (cheap, but can be inaccurate) or an external clock (costs extra, but can be much more precise). The Butterfly uses the interesting method of doing both. It has an external watch crystal that runs at 32768 beats per second — way slow for a computer, but very cheap and accurate. It uses this external crystal to calibrate the internal oscillator to run at 2 MHz. This provides us with a fast and accurate CPU clock and gives us the opportunity to use the crystal to generate pulses for a real time clock.

Think for a moment about the watch crystal frequency 32768. Seem weird? Well, remembering our last Workshop on binary numbers we see that it is binary:

Binary 1000 0000 0000 0000

But more importantly, 32767 — one beat short of 32768 is:

Binary 0111 1111 1111 1111

If we think electronics, we note that the highest bit changes from 0 to 1 once each second, so if we hook up a circuit that can keep a binary count (piece of cake) that can interrupt our code each time this bit changes from 0 to 1, then we can keep a count of seconds. Our main program will run along merrily doing whatever it does and once each second, we can have the current state stored, run an interrupt handler that can add one second to an external seconds variable, and then restore the main program state which will resume whatever it was doing —

unaware that a second has passed. That is, until it gets to some code that checks the external seconds variable against the local (automatic) seconds variable that it uses so that it would note that a second has passed and do whatever it does for that event. For instance, change the seconds value on the Butterfly LCD.

We will simplify our lives a bit by using the library libsmws7.a (see end of article for download information) that hides all the timer interrupt and LCD driver stuff. (You are welcome!)

Converting Computer Time To Human Readable Time

We can keep a count of seconds, but what good does it do us if our watch reads 40241? If the count started at midnight, then this number of seconds would indicate that the time is ten minutes and 41 seconds after 11:00 in the morning. So, we are going to need to do some computing to convert the count to something we can read.

BCD — Binary Coded Decimal

Binary Coded Decimal is a coding trick (or 'algorithm' for the more OCD among us) that eases the storage and conversion of binary numbers to decimal numbers. Say you have a count of the watch crystal beats in binary and want to display this number on an LCD in human readable decimal numbers. Using BCD, we can divide an eight bit byte into two, four bit nibbles and store them as single decimal integers — 0 to 9 — in each nibble. Since 9 is the largest decimal digit and we can store two digits per byte, 99 is the largest decimal value we can store. Yes, using a byte to encode a maximum value of 99 when it could encode up to 256 values wastes space, but it provides a good way to store human readable decimal digits.

If a decimal number in a byte is less than 99, we can convert it to a BCD byte using the following algorithm (or 'trick' for the less OCD among us):

Set the initial byte (`uint8_t`) to some decimal two-digit value:

```
uint8_t initialByte = 54;
```

Declare a variable for the upper nibble value:

```
uint8_t high = 0;
```

Count the tens in `initialByte`:

```
while (initialByte >= 10)
{
    high++;
    initialByte -= 10;
}
```

After this runs, the initialByte now contains only the ones integer from the original byte and 'high' variable contains the tens, that is: high = 5 and initialByte = 4. We combine the high and low nibbles to get the converted byte:

```
convertedByte = (high << 4) |  
    initialByte;
```

You do remember the `<<` shift operator from an earlier workshop, don't you? Here it moves the high value into the high nibble. The `|` OR operator then combines it with the initialByte which contains only the low nibble.

Converting A Byte To The ASCII Equivalent Decimal Character Using BCD

We define two bytes – tens and ones – and a third byte – number – which we set to a value in the range of 0 to 99:

```
uint8 tens = 0;  
uint8 ones = 0;  
uint8 number = 54;
```

We use the character to BCD algorithm written as the function `byte2BCD2(uint8_t)` to convert the 'number' to the BCD equivalent in tens:

```
tens = byte2BCD2(Number);
```

Now tens has the BCD of the tens in the upper nibble and of the ones in the lower nibble.

We can convert this to an ASCII character for the integer by remembering that the numerical value of the ASCII character '0' is 48 and each following character value is a simple increment of the previous one. Meaning that adding the number 4 to the value of the ASCII character '0' – which is 48 – yields the ASCII character '4' ($48+4 = 52$ which is the ASCII code value of the character '4'). This is a good time to look at the ASCII chart included in this month's workshop downloads. So, the conversion of a decimal integer to its ASCII equivalent character code is the simple addition of 48 to the decimal integer.

Since the `byte2BCD2` function loaded both the tens and ones parts of the number into the high and low nibble of tens, we need to extract the ones and the tens so that we can add 48 (ASCII '0') to get the ASCII characters for Number:

```
// Load the ones variable with  
// the high and low nibble  
ones = tens;  
  
// Mask off the high nibble  
// and add 48 ('0') to get the ASCII  
ones = (ones & 0x0F) + '0';
```

Finally, we get the tens by right shifting the byte

four-bits, which we use as the ASCII character offset:

```
// Shift the high nibble to the low nibble  
// and add '0' for ASCII  
tens = (tens >> 4) + '0';
```

We'll use these ideas in the `showClock` function in the software.

The Real Timer Clock Software

Oh, great! Now that we've gotten some basics down, we are out of space again. Looks like the detailed software discussion will have to be deferred to a supplement where we will discuss creating functions to keep track of seconds, minutes, and hours; show them on the LCD; and set an alarm time and when that time comes, beep the Butterfly piezo element. We will have the source code and two supplements for this workshop: *Smiley's Workshop 7 – Supplement 1: Some More C Syntax*; and *Supplement 2: The Butterfly Alarm Clock Software* available in the `workshop7.zip` file from Nuts & Volts at www.nutsvolts.com or www.smileymicros.com.

Next month, we will finish the introductory C syntax and learn how to use the Butterfly sensors to measure light, temperature, and voltage. **NV**

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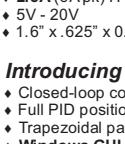
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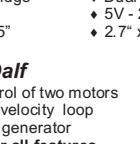
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■ BY L. PAUL VERHAGE

THE GREAT PLAINS SUPER LAUNCH 2008

GPSL — OR THE GREAT PLAINS SUPER LAUNCH — is the largest annual amateur near space launch, and takes place every summer. This year, Near Space Ventures and CAP'n'Space hosted GPSL in Liberty, MO on August 1-2. The site was the White Science Center on the attractive campus of William Jewell College. Here's what you missed if you didn't attend GPSL this year.

BASE

The first speaker was Howard Brooks of DePauw University in Greencastle, IN. The university's near space program is named Balloon Assisted Stratospheric Experiments, or BASE. BASE provides a near space platform for students interested in performing experiments in a space-like environment. Howard spoke about one of the flights from earlier this year, BASE 20. Weather conditions were cold and windy, but BASE 20 was launched as planned. Initial indications were that its ascent rate was lower than calculated; only 400 feet per minute compared to a more typical ascent rate closer to 1,000 feet per minute. The lower than expected ascent rate wasn't a problem, it just meant the DePauw team would recover their near spacecraft farther away from the university than originally planned — possibly in Canada. So based on that information, the chase team headed back home.

BASE 20 eventually reached an altitude of 78,000 feet, approximately six hours after launch. Splashdown occurred near the north shore of Lake Erie. The lake's northerly currents brought most of BASE 20 to shore where a Canadian recovered it and shipped the remains back to DePauw. Onboard BASE

20 were several student experiments, one of which included eggs. The eggs' hard freeze in near space cracked the shells and let the contents ooze slightly. After sitting in Lake Erie water for a while, the eggs became none too appetizing. In the words of DePauw student Tammy Kjonaas, "If you fly eggs and the capsule gets lost, you may be sorry you launched eggs."

INTERNATIONAL DARK SKY ASSOCIATION

The second speaker was Robert Wagner; he addressed the issues of light pollution. Take a look at the night sky from your front yard next summer. Overhead, going roughly north to south, you should see the Milky Way. However, if you live in a town or city with lots of light, you won't see this sight. Robert suggested several steps we could implement at home to improve this situation. If you'd like to find out more about this, then check out the Dark Sky website at www.darksky.org.

HARP

Jeff Dailey of Taylor University was the third speaker. Taylor has been ballooning for the last six years,

but unlike most, they don't rely on amateur radio for tracking and telemetry. Instead, the Taylor program HARP (High Altitude Research Program) uses a one watt ISM radio to send a continuous stream of data from their command pod. The rest of their flight electronics include 10 ADC channels, eight digital inputs, and two digital outputs.

The Taylor electronics let them control the altitude of their balloon via a machined valve fitted inside the balloon neck. After a quick ascent to the desired altitude, a command from the ground vents a small amount of helium from the balloon and slows it down. A later command vents more helium to begin the balloon's descent.

Last year, Taylor announced plans to create a balloon-based mesh network spanning the Midwest. The Taylor-designed pods were distributed to eight universities and carried weather instruments and networking radios. Taylor coordinated all eight launches. During the mission, five of the eight balloons linked up creating a network which enabled transmission of data packets on one watt from as far as 270 miles. Over 100 people were involved with this successful effort and Taylor is planning a more ambitious network involving 21 institutions for 2009.

BILL BROWN

Bill Brown, the father of modern American near space ballooning, was next. Bill's presentation covered a variety of topics because he basically is a master experimenter.

Bill is also a fan of long duration near space flights. Normally, a flight like this can only be accomplished with an expensive polyethylene balloon. However, Bill has perfected techniques involving less expensive latex weather balloons. In one of his techniques, he seals the balloon's neck with a PVC pipe containing a 1/16 inch diameter hole. The hole lets helium slowly vent out of the balloon, gradually slowing down its ascent rate. The decrease in ascent rate is so slow that the balloon still reaches near space altitudes before the sun's ultraviolet rays degrade the balloon to the point of bursting. One of Bill's flights reached an altitude of 107,000 feet in its 17-1/2 hour flight (compared to a nominal 100 miles for a flight like this).

Bill recommends launching a flight like this in the spring and autumn when the stratospheric winds begin changing their direction (this is called the stratospheric turn around). That way, the balloon drifts slowly and recovery takes place closer to the launch site rather than across many miles.

One of the neatest things Bill presented this year was the Find Me Spot, a personal GPS tracker. As he explained, SPOT transmits its GPS location to Global Star satellites every 10 minutes. From experience, Bill discovered that it didn't transmit its position above 60,000 feet. However, once the near spacecraft carrying Find Me Spot descended below this altitude, Find Me Spot began transmitting its location again. Even upside down, SPOT transmitted its GPS position to the Global Star Satellite overhead. While a bit spendy at \$169 for the unit and \$150 annual fee for unlimited use, SPOT may be the ultimate insurance policy for a near spacecraft.

■ Find Me Spot, the personal satellite tracker. (Carry one of these with you and friends will know where you're at every 10 minutes.)

■ Bill Brown discussing his many near space activities.

EDGE OF SPACE SCIENCE

Mike Morgan of Edge of Space Sciences (EOSS) was the next speaker. He led a discussion about using hydrogen to fill latex weather balloons.

Like many commodities, helium prices have recently begun to rise (pun intended). While helium is the second most abundant element in the universe, its existence on earth comes only from the decay of radioactive isotopes underground. As natural gas reserves are exhausted or become too costly to pump, the availability of helium will continue to decrease, further raising its cost.

When hydrogen-filled balloons get mentioned, people invariably think of the Hindenburg. However, hydrogen wasn't the problem with this great airship; the problem was its flammable skin. As long as proper safeguards are used, hydrogen is a safe filling gas for weather balloons. This doesn't mean there aren't risks associated with hydrogen.

Unlike helium, hydrogen is flammable in concentrations ranging from 4% to 74% (a very wide range). Hydrogen requires low energy to ignite and may even self-ignite with a little static electricity. Its flame is nearly invisible to the naked eye and it burns hot.

Mike recommended to never vent hydrogen from a tank into the atmosphere. So, never drain a tank of hydrogen by opening its valve;



instead, bring it back to the welding supplier for disposal.

Other suggestions were to use a single tank at a time to fill a balloon; do not connect several tanks together into a single manifold. Use stainless steel or brass fittings; not plastic ones as they can generate static discharge as dry hydrogen flows through them.

Ground all filling equipment with at least three stakes to the ground. This includes grounding the person handling the balloon filler with a grounding strap. In addition, fill the balloon slowly, as a lower flow rate decreases the chances of electrostatic build-up.

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CAP'n'Space
capnspac.org

Bill Brown
home.hiwaay.net/~bbrown

There's more about the Great Plains Super Launch at
www.superlaunch.org



Since filling tanks on more humid days helps reduce the risk of static, perhaps spraying the interior of the balloon with water and detergent solution to increase its internal humidity level could be a smart idea. Those around the balloon should wear gloves, long sleeve shirts, and head cover with goggles or a face shield. Since hydrogen burns fast and upward, filling crews around and below the balloon need protection.

In the old days, people around tanks of hydrogen swept a straw broom around them to locate possible burning hydrogen leaks. Today, we use IR thermometers to detect the invisible flames of burning hydrogen. Since they are so inexpensive these

days, every near space group using hydrogen should carry at least one.

THE FAA

The last speaker was Veronica Bailey of the FAA (Federal Aviation Administration). A 22-year career employee, her expertise is in education these days. Veronica manages air shows and career fairs for the FAA. She also partners with CAP, ROTC, Project Lead the Way, Boys and Girls Clubs, and some universities with aviation programs. One especially interesting thing she talked about is that the FAA is about to face a shortage. There are too many employees nearing retirement age and the agency is looking to hire

NOTE: All PCB patterns and files are available on the *Nuts & Volts* website at www.nutsvolts.com.

5,000 new employees a year for the next five years — just to replace retiring traffic controllers. This sounds like a career opportunity to me!

This concluded Friday's presentation, after which Near Space Ventures gave the audience a weather briefing for Saturday's flights. If you'd like to view some of the activities from this day, go to nearsys.com > Amateur Radio High Altitude Ballooning > Data from Past Flights > 2008 > NearSys 08A for a complete mission report and video.

Onwards and Upwards,
Your near space guide **NV**

REEFING PARACHUTES

I do want to mention reefing parachutes this month. Reefing prevents a parachute from fully opening at high altitude. Then, once it has descended to a lower altitude, the parachute is allowed to fully open. A reefed parachute lets the near spacecraft descend faster early in the recovery while it's at high altitude and not a hazard to those on the ground. Then, when near touch-down, the parachute completely opens, slowing the near spacecraft to a safe landing speed. A quick drop from high altitude prevents the near spacecraft from drifting quite as far and puts the recovery zone closer to the launch site. The reefing concept I describe is actually untested; however, it should work well in near space applications.

Using a 2N3904 NPN transistor allows a low power source like the piezo alarm of an inexpensive stop watch to trigger the line cutter. To modify a stop watch for this purpose, you'll have to open it up and remove the piezo element of its alarm. The piezo element should drop right out, exposing the two springs used to make electrical contact with it. Solder wires to both springs. (I found inserting a bared wire into the spring is a great way to make the connection.) Then, set the alarm and measure the polarity of the wires when the alarm beeps. You need to identify which is positive and which is negative. The positive wire attaches to the left side of the line cutter PCB, at the pad marked signal. The negative wire attaches to the pad marked ground. The relay in this design is a five volt RadioShack reed relay, so the line cutter needs four cells, or six volts to operate. Alternatively, the line cutter's three wire cable could connect to a microcontroller project board like the Parallax Homework board. A separate battery provides the power for the nichrome line cutter.

That cable is the two wires on the right side of the PCB.

The reefing line is

■ The line cutter suitable for control by a variety of devices that was used successfully in the past to terminate two near space flights.



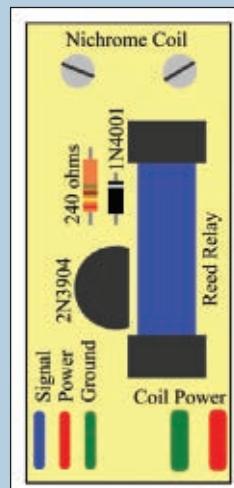
made by threading Spectra kite line through all eight twill tape loops at the bottom of the parachute canopy and the nichrome coil of the line cutter. I think it might be beneficial to add additional twill loops to the edge of the canopy. Having additional loops for the reefing line to pass through will more fully restrict the opening of the parachute. The Spectra kite line is then tied to form a loop smaller than the diameter of the fully opened parachute. Now when the balloon bursts, the reefing line will prevent the parachute from opening fully. The partially opened parachute still creates drag, but not to the extent that it would fully open. Then at some later time, a stop watch alarm or a microcontroller triggers the line cutter and it melts the reefing line. This then allows the parachute to fully open.

Now, to mount the line cutter. I've attached line cutters, batteries, and a timer to the apex of the parachute with no ill effects. I believe the battery and timer for the line cutter should be mounted there and the line cutter be allowed to dangle down the side of the canopy. To restrict the movement of the line cutter and its wires, a few small twill tapes should be sewn to the canopy to form a restraint. Sewing a cloth tunnel down the canopy in place of a couple of twill loops is probably too much trouble and overkill.

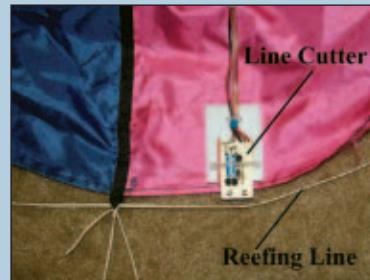
You'll find a ton more information on parachute design

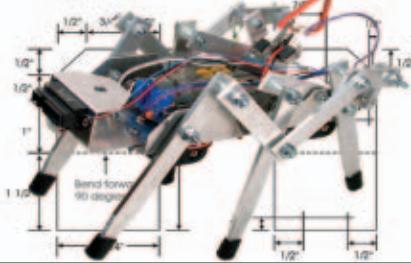
in the book, *Parachute Recovery Systems*, by T.W. Knacke. There's so much knowledge packed into this book that I've barely begun to scratch the surface.

■ The first test of a reefed parachute. Eventually, this system will be tested over the skies of Kansas.



■ Parts placement for the line cutter.





■ BY VERN GRANER

PNEUMATICS IN ROBOTICS

THE PRESSURE'S ON!

In taking some of my own advice from last month's Robo Resolutions article, this month we're going to try something new! Let's dip our toe into some possibly unfamiliar waters as we explore the world of electronically controlled pneumatic actuators for hobby robotic and animatronic mechanisms.

PLUMBING THE DEPTHS OF PNEUMATICS

In the world of experimental and hobby robotics, servo motors and solenoids tend to dominate the landscape. This is most likely due to the simplicity of using a single power source for all the functions (movement, computing, sensors, etc.).

However, in commercial automation and industrial assembly lines, many of the moving systems rely on compressed air and air-powered actuators of various types (**Figure 1**) to do the work. One of the interesting things you'll discover when you start to play with the components of a pneumatic system is that what you're actually doing is *plumbing*! Subsequently, you get to explore a whole new set of schematic symbols and terminology. To help you get started, I've included a link to some

■ Figure 1. Examples of typical pneumatic actuators.

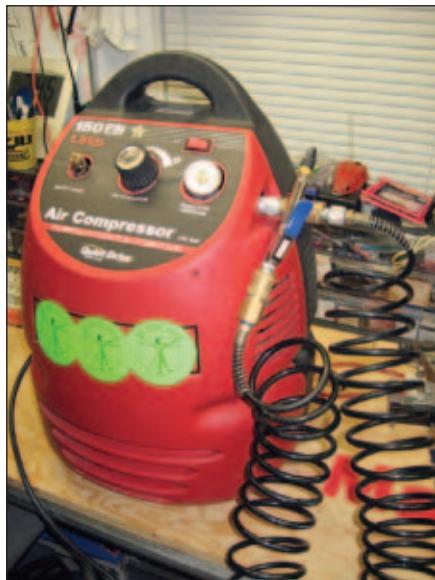


common pneumatic symbology in the Resources section.

THE BASIC PARTS OF A PNEUMATIC SYSTEM

Since there are plenty of great resources on the Internet to get you going with pneumatics, in this article I'm only going to give a quick overview of the basic parts you will need in order to start experimenting with pneumatics for your next robotic project.

■ Figure 2. A 1.5 gallon workbench portable air compressor. This unit features much quieter operation than most typical "pancake" type compressors.



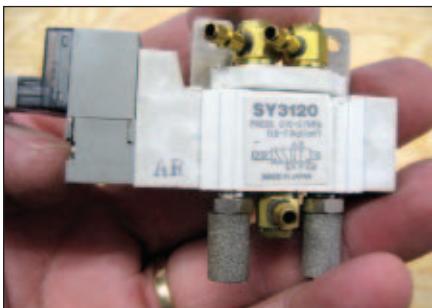
Compressor: (**Figure 2**) When using pneumatics, you need a ready supply of compressed gas. This is typically provided by an air compressor. Though many of the pneumatic systems incorporated into "battling" robots use high-pressure CO₂ systems (for both strength and portability), I wanted to have a non-exhaustible air source that didn't require me to get tanks refilled. For my experimentation, I purchased a 1.5 gallon, 150 psi

■ Figure 3. An air pressure regulator. PLEASE NOTE: A *flow* regulator is not the same thing as a *pressure* regulator! A flow regulator simply limits the speed the air may pass through the device and does NOT limit pressure! Be sure to read the description carefully before making a purchase so you don't end up with the wrong part!

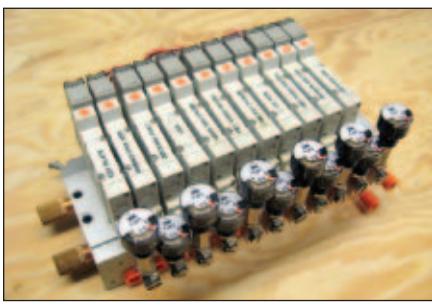




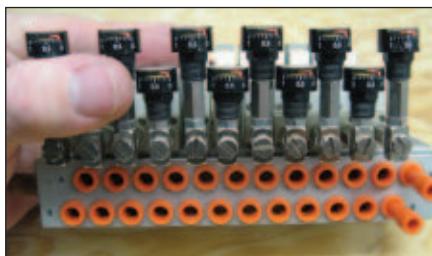
■ Figure 4. A 12 VDC five port, two position solenoid valve.



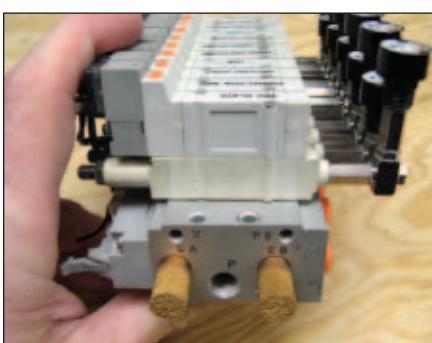
■ Figure 5. A 12 valve pneumatic manifold with eleven 24 VDC five port, two position valves installed.



■ Figure 6. The actuator connector section of the valve manifold. These are easy to use "press collar" type connectors making hook up and experimentation easy. The last two ports are blocked with plugs as the manifold only has 11 of the 12 sockets used.



■ Figure 7. Sideview of the manifold shows the Exhaust A and B mufflers in place and the connection point for air pressure (labeled P).



air compressor from Sears for about \$125. I figured the compressor might come in handy as a workbench accessory, and boy was I right (see the compressor sidebar)!

Regulator: (**Figure 3**) Though most compressors come with a regulator built in to the unit itself, I found it's handy to be able to tailor the amount of air delivered to each pneumatic device. Also, in the event that you have multiple pneumatic devices being powered by a single air source, having a regulator at each device allows you to run your main air lines at a higher pressure and then adjust the pressure at each device to the minimum required to operate a given actuator.

For example, you could run your main air line at a pressure high enough to allow one device on your system to lift a heavy load, yet still allow another device on the same feed line to drop the pressure for a small cylinder performing more delicate work. It's a good rule of thumb to use only as much pressure as is necessary in order to get a given device to function. Having regulators on each device allows you to avoid having the highest pressure requirements dictate pressure for all devices on the same air feed.

Solenoid Valve: (**Figure 4**) In order to operate a pneumatic actuator, you need to be able to control where and when the air flows to the device. A solenoid valve allows you to use the presence or absence of power to route air pressure. Typical industrial solenoid valves use 24 volts to operate (though 12 volt and 110 VAC solenoid valves are available) and come in many different configurations. My preferred solenoid valve is a five port, two way solenoid valve such as those available from Burden's Surplus Center (www.surpluscenter.com).

This type of valve has a port for pressure (labeled P) and then has two ports for a dual-acting cylinder labeled A and B. When pressure is applied to the P port, it is sent to the A port and the B port is routed to the exhaust port EB. When power is applied to the solenoid, pressure is

re-routed to the B port while the A port is then routed to the exhaust EA port.

A five port, two position valve – when combined with a dual-acting cylinder – provides a positive return, i.e., it doesn't rely on a spring or gravity to return the cylinder to its start position. It's also very efficient as it only uses the amount of air held in the air cylinder's interior for each activation. Using less air reduces the compressor requirements and will also reduce the number of cycles your compressor will need to run to keep sufficient air available as the pneumatic actuator is operated.

Sometimes a group of valves are placed on a manifold so that you only need to provide one source for air pressure to serve multiple pneumatic actuators (**Figure 5**). From my contacts through The Robot Group here in Austin, I was lucky enough to end up with a couple of these manifolds that were removed from a large industrial test machine. The manifolds hold multiple five port, two way valves with press-fit connectors for the A and B ports (**Figure 6**).

In addition, all exhaust ports are ganged so you only have two exhaust vents to deal with. Depending on the pressure, the exhausting air can be fairly loud. Many systems use air baffles or mufflers in order to reduce the noise levels (i.e., the hiss of the exhaust). In the manifold I have, all the valve exhausts are sent to single exit points labeled EA (Exhaust A) and EB (Exhaust B). These ports have brass mufflers to lower the noise levels produced when the device is in operation (**Figure 7**).

The sound pressure levels generated by a device are an important consideration as long term exposure to loud sounds can lead to hearing loss. In some cases, the sound made by the venting gas could be detrimental to the operation of the finished device itself. If you're using pneumatics in an animatronic device to sync jaw motions to a sound track or if you're using a pneumatically controlled musical instrument of some type, the hiss of air may detract from the performance of the unit. In these

cases, routing the exhaust air through a muffler is the simplest way to avoid the hiss associated with actuator air being vented.

Pneumatic Actuator: Typically, air cylinders are used to get motion from compressed air. With air cylinders, you usually see two types: single acting and double acting cylinders. A single acting cylinder will have a single port for air to enter/exit (**Figure 8**). These cylinders usually rely on a spring to return them to a start position and will move to the end of their travel when air is applied. They will return to their start position when air pressure is exhausted.

Double acting cylinders have two ports, typically designated A and B. When pressure is applied to the A port, the cylinder rod will move to the end of its travel. You then apply pressure to the second port (typically designated B) in order for the cylinder rod to return to its start position. Also, you must remember that if pressure is applied to the A port, the B port *must* be routed to exhaust (and vice versa) in order to allow the cylinder to move.

In most cases, single and double acting cylinders will move a rod in and out in order to perform work. The rod may extend from only one end of the cylinder or, in some cases, may extend from both ends (**Figure 9**). Some cylinders are mounted in rigid enclosures with guide rods that will allow the device to move precisely without rotating or deviating from its path.

There are also rotary actuators that will rotate from one position to another (i.e., 0 to 180 degrees) when air is applied (**Figure 10**). These are sometimes used to rotate a turntable to position parts or can be used to open/close a door on a mechanism.

Air Reservoir: (**Figure 11**) Though this is usually optional, some designs may call for a higher volume of air than may be provided by the compressor tank itself. If you want to store up "extra" or if your device is at the end of a long hose run, you can place an air reservoir near your solenoid valve and cylinder in order to insure a sufficient supply of air for a

given pneumatic assembly.

SCARY AIR!

My first foray into using pneumatics was when I was building props for my haunted house – the Spiders Preyground (see Resources). I wanted to build a prop affectionately called a "Trash Can Trauma." This is a specially modified trashcan that can pop its top on command to give folks a good startle. I researched designs online and they all used pneumatics to provide the motive force to get a fast acting and reliable pop-up action. After looking over a few plan sets I found on the Internet, I started compiling a list of the things I would need to make my own TCT.

I found everything I needed for my first pneumatic prop in my junk bin, on eBay, and through a couple of surplus component websites. In short order, I had a 17 inch Bimba air cylinder, a Surplus Center five port, two way solenoid valve, and a pressure regulator. I mounted all the parts on a piece of scrap wood (**Figure 12**) and then added some simple electronics (solid state relay, colored light bulb,

■ Figure 8. A 1.75" single-acting, spring return pneumatic cylinder.



■ Figure 9. A dual-acting guided cylinder with 1" of travel.



and a strobe light). I then placed the device into a galvanized trashcan. When connected to power and given only 45 psi of air, this made for a very fun and scary Halloween prop. Simply press a button and the trashcan lid pops up with a scary skull

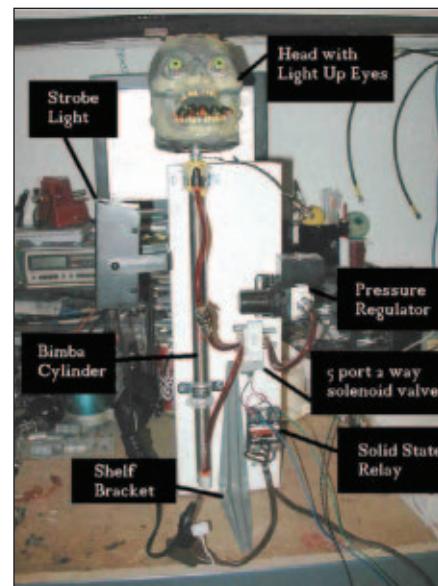
■ Figure 10. A Festo brand adjustable rotary actuator with 180 degrees of rotation.



■ Figure 11. A typical, inexpensive five gallon air reservoir.



■ Figure 12. The trashcan pop-up mechanism before mounting.





grinning mischievously at you!

After I had successfully tackled the TCT, I decided to try to animate a much larger prop. I crafted a spider body out of PVC pipe with a pneumatic cylinder to raise and lower the front of the prop (**Figure 13**). With legs attached, the width was just over 20 feet! Once wrapped in black fake fur, placed in our darkened dining room, and revealed by a well timed curtain drop, the spider made for a fantastic finale for our haunted

■ Figure 13. Close-up of the 17" pneumatic cylinder used to cause the giant spider to bounce and lunge.



house. See the Resources section for a video of this prop in action.

A SIMPLE PNEUMATIC GRIPPER

So now that we're familiar with some of the basic components of a pneumatic system and their usage, I'm going to walk through the creation of a simple pneumatically activated gripper using a toy robot arm and a small double acting air cylinder. The finished gripper is actually

■ Figure 15. The handle and trigger after being removed.



■ Figure 14. A plastic robot arm toy.

DIY vs. Safety

While working with various home and commercial haunted houses over the last few years, I've seen many pneumatic systems used to power props. Some used home-brew actuators. A bit of digging on the Internet will reveal a plethora of designs for converting non-pneumatic devices for pneumatic use. Some of the most common are plans to convert a bicycle tire pump or a screen door closer mechanism into an air cylinder. It's also easy to find plans that show how to build pneumatic devices out of PVC pipe (pistons, cylinders, and air reservoirs are the most common).

Before you head down this path, take a moment to consider that using compressed air can be very dangerous! As commercially-built air cylinders are widely available on the surplus market at bargain-basement prices, I strongly discourage the use of non-pressure rated or DIY devices in pneumatic systems. Not only will converting or creating an air pressure operated device consume your time, but in many cases there are additional hidden costs in air fittings/adapters and the like that can make the DIY device more expensive (yet less reliable) than a commercially built unit!

If you are planning to make a device to which people may be exposed (i.e., a pop-up scare in a haunted house), please make sure you use only commercially-produced cylinders and actuators to keep everyone safe!

capable of doing simple work and is very straightforward in design, construction, and operation.

I started with an inexpensive plastic robot gripper from a toy store (**Figure 14**). I removed the handle (**Figure 15**) and then using a Dremel tool, I cut off some of the plastic arm to reveal more of the actuator rod (**Figure 16**). I then bent the actuator rod into a Z shape (**Figure 17**) and did a test fit on my pneumatic cylinder.

With the arm all prepped, it was time to create a bracket to hold the cylinder to the arm. I used a "nibbler"

■ Figure 16. Cutting the end of the robot arm reveals more of the push-rod. Remove the "holed" section to increase durability.



■ Figure 17. The push-rod after being bent into a "Z" configuration. An "eye" has been added to the end of the cylinder for connection to the rod.



■ Figure 18. Using a metal "nibbler" to cut an old PC cover plate into a suitable bracket for the pneumatic cylinder.



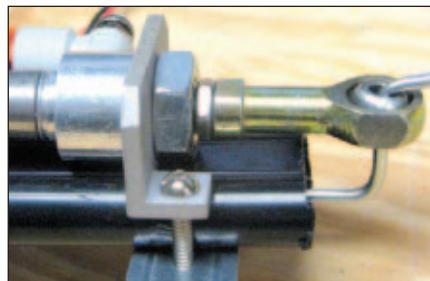
tool to cut a spare back plate from a PC case (**Figure 18**). I then placed the cylinder at the end of the arm and put two screws through to clamp the cylinder into place (**Figure 19**).

Next, I picked a Surplus Center SY3120 12V five port, two position solenoid valve from my pneumatic parts junk bin and assembled it with a barb style input for pressure, barb style connectors for A and B outputs, and dual exhaust mufflers. I used flexible pneumatic rubber hosing to connect the valve to the air cylinder on the arm (**Figure 20**).

To get air pressure for the system, I put together a regulator/adapter to connect my workbench compressor to the pneumatic arm. I joined a 1/4" NPT (common connector on most compressors) to an 1/8" barb fitting adapter, connected it through a short piece of hose to the regulator, then fitted a press fit collar adapter to the output side of the regulator (**Figure 21**). Lastly, to control the solenoid valve I connected a 12 volt power supply with a N.O. switch to the 12V connector of the solenoid valve.

I fired up the compressor and set the regulator for about 35 psi. I was then able to use the N.O. pushbutton switch to open and close the gripper quickly and reliably. In order to help visualize the operation of the gripper, I've created a short video showing the pneumatic arm in operation on my workbench (again, see Resources).

■ Figure 19. The pneumatic cylinder attached to the robot arm with screws.



IT'S YOUR TURN NOW!

If you decide to build an air-powered robotic device of some sort, you'll be in good company. One of my first jobs right out of high school was as an Animatronics Technician for a division of Atari (I worked on the singing/dancing robots for a *Chuck-E-Cheese Pizza Time Theater*). Most all of the animatronic devices used for pizza parlors and theme parks are pneumatically actuated.

Another factor to consider about pneumatic actuators is that they are usually compatible with harsh environments that would normally destroy electronics. I've seen dual acting cylinders operate without failure while completely immersed in water.

If you haven't done so already, I hope this article will inspire you to experiment with pneumatics in your robotic creations. As always, if you have any questions or comments, please feel free to contact me directly via email at vern@txis.com **NV**

A Bench-side Compressor

For years, I used small cans of compressed air that were actually full of liquid that would vaporize when released. Not only is this "canned air" expensive, the fumes released into the atmosphere may be dangerous to your health, and possibly to the environment as a whole. When I started experimenting with pneumatic cylinders, I decided to purchase a compressor and now I can't imagine how I ever lived without one. Not only can it be used to replace those little cans of air (at \$4 a pop!), but it can be used to drive low cost nail guns, inflate tires, fill up air mattresses, and clean out PC cases and power supplies.

Now that I've got a compressor under my workbench, I wouldn't go without one! The compressor I purchased was only \$125 but I'm sure it has paid for itself many times over. One caveat, however, would be noise. Some compressor designs are louder than others so I recommend that you ask for and compare the DBA levels of any unit you are considering purchasing. The unit I settled on was sold by my local Sears store and featured "QuietDrive" technology so it produces less noise than many other types.

■ Figure 20. The finished pneumatic gripper with solenoid valve connected. Those with sharp eyes may notice that I swapped the 90 degree barb-connectors for straight-through connectors so the assembly would lie flat for the photo!



■ Figure 21. All the parts to connect the 1/4 inch "NTP" style workbench compressor to the robot arm.



RESOURCES

- The Robot Group
www.robotgroup.org

- Common symbology in pneumatics
www.rosscontrols.com/symbols2.htm

- Source for pneumatic valves and cylinders
www.surpluscenter.com

- Spiders Preyground Video 2004 showing Trash Can Trauma and Giant Spider
www.youtube.com/watch?v=ICf6EjPZtNI

- Spiders Preyground Video 2005 showing rotary pneumatic actuator "Spider Slammer" and Giant Spider
www.youtube.com/watch?v=ICf6EjPZtNI

- Video of the pneumatic arm in operation
www.youtube.com/VernGrainer

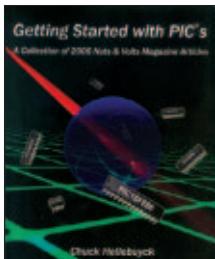
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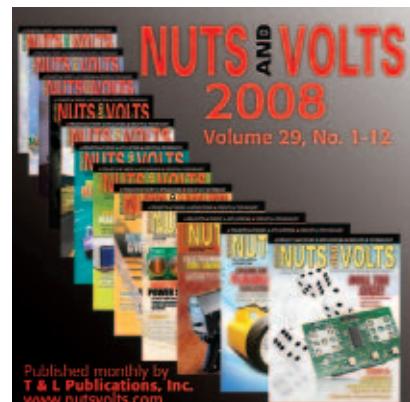
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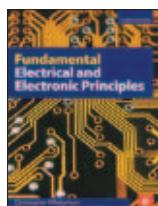


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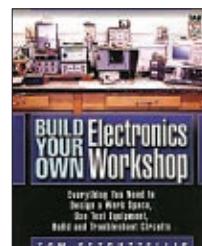


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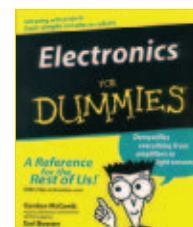
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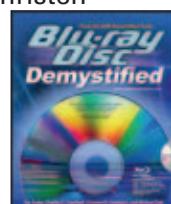
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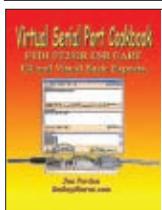
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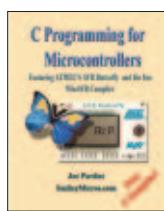
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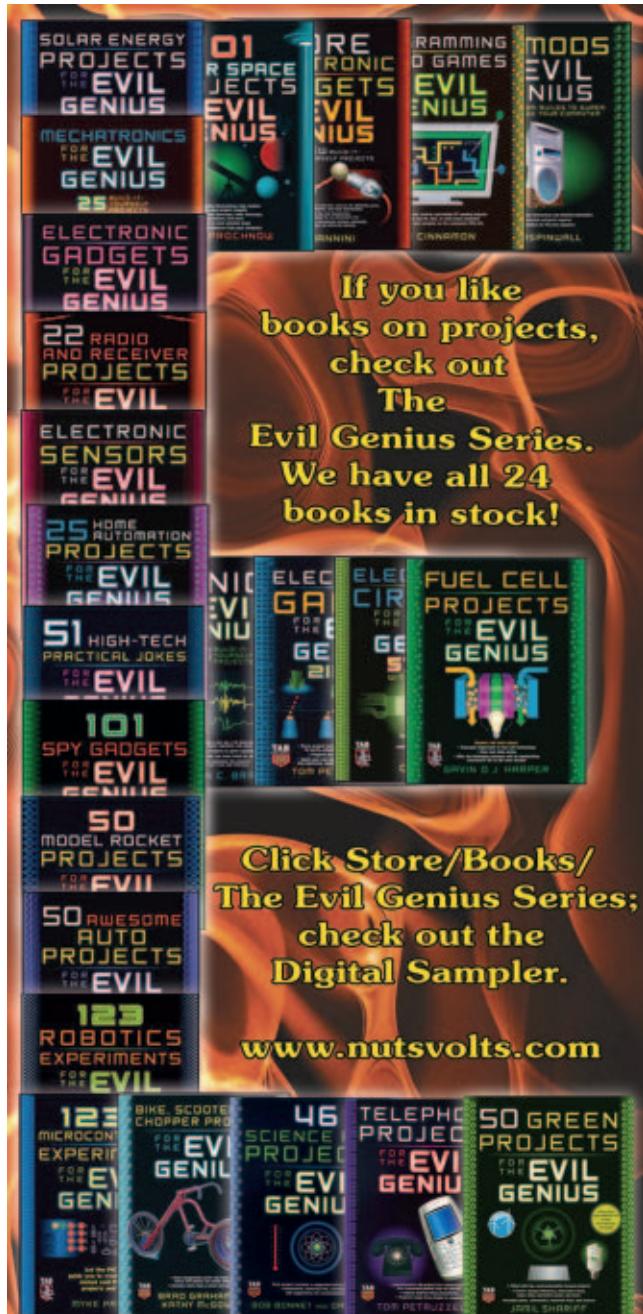
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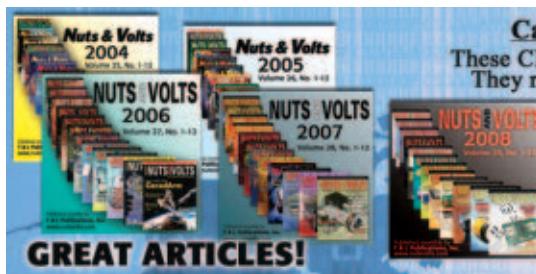


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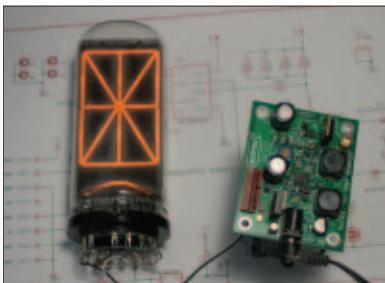
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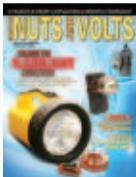


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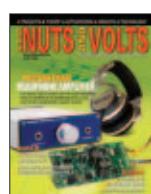
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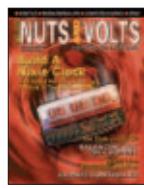
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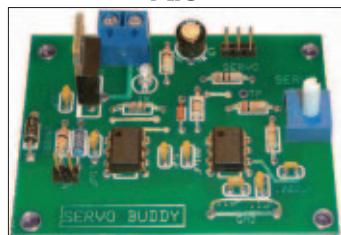
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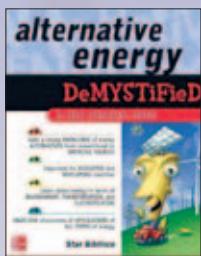
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Alternative Energy Demystified by Stan Gibilisco

Publish Date: October 23, 2006

The fast and easy way to get up-to-speed on alternative energy. Because of current events, geopolitics, and natural disasters, the cost of fuel is front and center in our lives. This book provides a concise look at all forms of energy, including fossil fuels, electric, solar, biodiesel, nuclear, hydroelectric, wind, and renewable fuel cells. You will get explanations, definitions, and analysis of each alternative energy source from a technological point-of-view. **\$19.95**



ALTERNATIVE ENERGY SECTION

Kill A Watt Meter



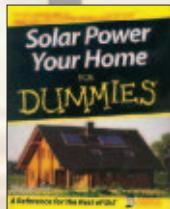
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Solar Power Your Home For Dummies

by Rik DeGunther
Publish Date: Dec 2007

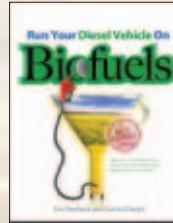
This friendly, hands-on guide is packed with tips for making your home more energy-efficient through solar power—and helping the planet at the same time. You'll see how to survey your home to determine your current household energy efficiency and use, and evaluate where solar power would best benefit you. You'll also calculate what the return on your investment will be before you make any decisions. **\$19.95**



Run Your Diesel Vehicle on Biofuels

A Do-It-Yourself Manual

by Jon Starbuck, Gavin D J Harper
CONVERT TO BIODIESEL FOR A MORE ENVIRONMENTALLY FRIENDLY RIDE! Run Your Diesel Vehicle on Biofuels has everything you need to make the switch from expensive, environment-damaging carbon fuel to cheap (and, in many cases, free), clean fuel for your vehicle. Practical and decidedly apolitical, this unique guide focuses on technical details, parts, and instructions. **\$24.95**



Build Your Own Electric Vehicle

by Seth Leitman, Bob Brant

Publish Date: October 10, 2008

Go Green-Go Electric! Faster, Cheaper, More Reliable While Saving Energy and the Environment!

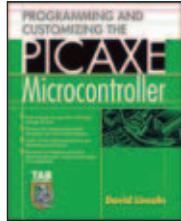
This comprehensive how-to goes through the process of transforming an internal combustion engine vehicle to electric or even building an EV from scratch for as much or even cheaper than purchasing a traditional car. The book describes each component in detail—motor, battery, controller, charger, and chassis—and provides step-by-step instructions on how to put them all together. **\$29.95**



Programming and Customizing the PICAXE Microcontroller

by David Lincoln

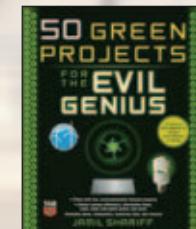
Here's everything you need to harness the power of PICAXE, the inexpensive yet versatile chip that's taken the electronics community by storm. This beginner-friendly guide from IT pro and PICAXE expert David Lincoln shows you just what Revolution Education's PICAXE can do and helps you make it do it! **Reg \$39.95 Sale \$34.95**



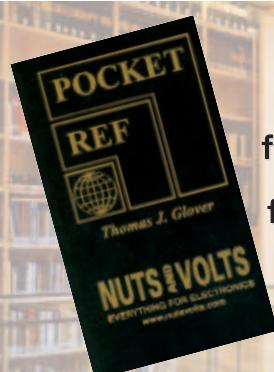
50 Green Projects for the Evil Genius

by Jamil Shariff

Using easy-to-find parts and tools, this do-it-yourself guide offers a wide variety of environmentally focused projects you can accomplish on your own. Topics covered include transportation, alternative fuels, solar, wind, and hydro power, home insulation, construction, and more. The projects in this unique guide range from easy to more complex and are designed to optimize your time and simplify your life! **\$24.95**



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READER FEEDBACK

continued from page 10

LIKING WHAT THEY CNC

Congratulations to Vern Graner on his review of the Fireball V90 Router kit in the December '08 Personal Robotics column.

I was surprised to see a CNC machine kit at a price below \$1K. The cheapest I've been able to find previously has been over \$2K. For example: <http://buildyourcnc.com/default.aspx>. His article skirts one problem in the low cost Cad/Cam/CNC arena. Something you might want to consider for a future article, e.g., the cost of the software.

When I acquired my Sherline mill almost 10 years ago, Sherline didn't sell a CNC package. (I got mine back then from Flashcut; they still sell one.) When Sherline did offer a CNC package, they went with the Linux-EMC solution for the same reason that I'm looking at it for my next system: zero cost. I'm looking at the combination of Ubuntu EMC, GCAM for the CAM part (http://gcams.jscx/index.php/Main_Page) and QCAD for 2D CAD (www.qcad.org/qcad.html). I'm still looking for a Linux based 3D CAD package; there are a number of possible candidates.

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I enjoyed your article about the Probotix Fireball V90 CNC Router. I make "techno geeky" clocks from discarded computer parts. I need a way to customize blank CD-ROMs or DVDs, and while there may be easier, less expensive ways, I'm intrigued with your review. To start with, I've used a PC with Windows for years and, of course, DOS.

I have lots of unused computers in my garage (30+) and would like to take the best/premium one of this group and possibly convert it to Linux. Based on your article, the EMC-2 route is a less troublesome way to go.

Larry

PRECISION PART

I could not find the component listing for L1+L2 in the parts list on your

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Precision Headphone Amp in the June '08 issue. Could you please tell me what value and P/N these SMT inductors are?

Bill Mack

Sure! Here you go:

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 2.5A 0805 0 0.06700

That's a Digi-Key number and the price is approx. 67 cents. Good luck!

Editor Bryan

MODIFICATION A SNAP

Would it be possible to modify Fred Eady's October '08 WIFI Hotspot project to be USB compatible so it could interface with Nikon DSLR cameras?

Kirk Davies

Yep. Just put an FTDI USB-to-serial IC on the board instead of the ST3232 RS-232 part.

Fred Eady

TECH FORUM



This is a READER-TO-READER Column.

All questions AND answers are submitted by *Nuts & Volts* readers and are intended to promote the exchange of ideas and provide assistance for solving problems of a technical nature. Questions are subject to editing and will be published on a space available basis if deemed suitable by the publisher. Answers are submitted by readers and **NO GUARANTEES WHATSOEVER** are made by the publisher. The implementation of any answer printed in this column may require varying degrees of technical experience and should only be attempted by qualified individuals. Always use common sense and good judgement!

All questions and answers should be sent by email to forum@nutsandvolts.com. All diagrams should be computer generated and sent with your submission as an attachment.

QUESTIONS

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- ① Circuit Design
- ② Electronic Theory
- ③ Problem Solving
- ④ Other Similar Topics

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- Comments regarding answers printed in this column may be printed in the Reader Feedback section if space allows.

>>> QUESTIONS

Meter Conversion

I am building a project that uses a 0-100 UA meter. Can I purchase a DATEL/MURATA 0-199.9 UA digital meter (LED) and use it in place of an analog style? I realize that I have to power it separately.

#2091

Mark Habian
Conneaut, OH

USB Speakers

Can a USB speaker — like a Harmon Kardon iSub 2000 — be rewired to use a regular audio input while still using the built-in amp?

#2092

Jerry Williams
West Bend, WI

Power Pac for HO Railroad

Does anyone know of any plans for controls to run several trains simultaneously on the same line, independently of one another?

#2093

Terry Murphy
El Cajon, CA

Regulators or Zener Diodes?

Many of us use the regulator devices 7805, 7812, etc., in our designs. What is the difference between these and using zener diodes? An internal circuit diagram would be helpful! When do you use a low resistance resistor in series with these devices?

#2094

Tom King
via email

Auto 12V to Laptop 19V Power

I'm looking for a circuit that can boost the 12V in a car to 19V, enough to run two laptops (batteries removed). It will have to provide at least 100W. I bought one off eBay but it is unstable with my laptops (shuts down randomly).

#2095

Craig

Hamilton, Ontario

Constant Current 30 VDC

I need a schematic for a 30 volt DC power supply running at a constant current of 800-900 microamps, adjustable.

I want to make colloidal silver of minimum particle size and the current flow through the solution must not exceed one milliamp. In the beginning, the resistance is very high through steam distilled water, but in time the resistance becomes progressively lower. The adjustable current flow must be held constant by the supply.

#2096

Phil Vogel
via email

Sensing AC Fan Motor

I'm looking for an easy way to sense when my home AC/heater fan is running (110 volts).

I have an electronic timed pump air freshener that I want to spray into the AC/heater plenum ONLY when the fan is running so it will carry the fragrance throughout the house.

#2097

Porter Sadler
Dunwoody



Peak Reading Voltmeter

How can I build a peak reading voltmeter or add-on unit for a VOM to read the peaks of a DC pulse? When troubleshooting ignition systems on motorcycles and marine engines, the peak voltage supplied by the various coils needs to be checked. A regular VOM always reads low. How can I catch the peaks?

With RPM as much as 14,000 and as many as 12 pulses per revolution, we are talking very short pulses. Testing is normally done at a cranking speed of 200 to 300 RPM. There can be as many as 12 magnets zinging by each coil per revolution.

#2098

Tony Altobelli
Grand Rapids

USB HDTV Tuner Hack

How hard it is to rewire or modify a USB HDTV tuner to work with a portable DVD player to watch HDTV programming from it or any other applications like making a portable HDTV tuner with a battery power source? I've written about this idea to many other sites and have had little to no responses positive or otherwise.

#2099

David Kichi

Inquiring Minds Want To Know!

Transformers, motor stators use stacks of thin (approx. 1/32") steel plates. Is this for manufacturing economics or is there a physics reason for using stacked plates?

Will using 1/16" plates instead of 1/32" plates affect performance? How much less efficient is aluminum wire versus copper for making transformers, stators, electromagnets?

Are there small solid-state relays capable of handling high voltage/high current surges through the switches (rail gun application)?

#20910

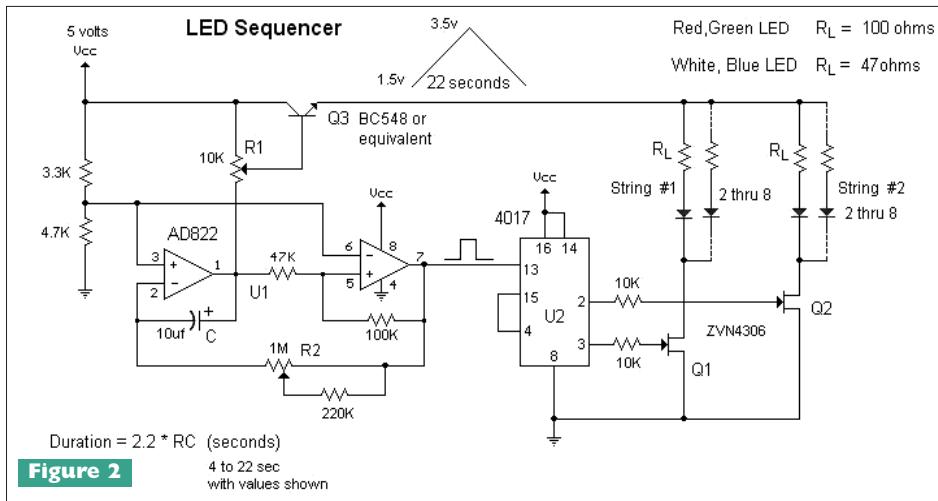
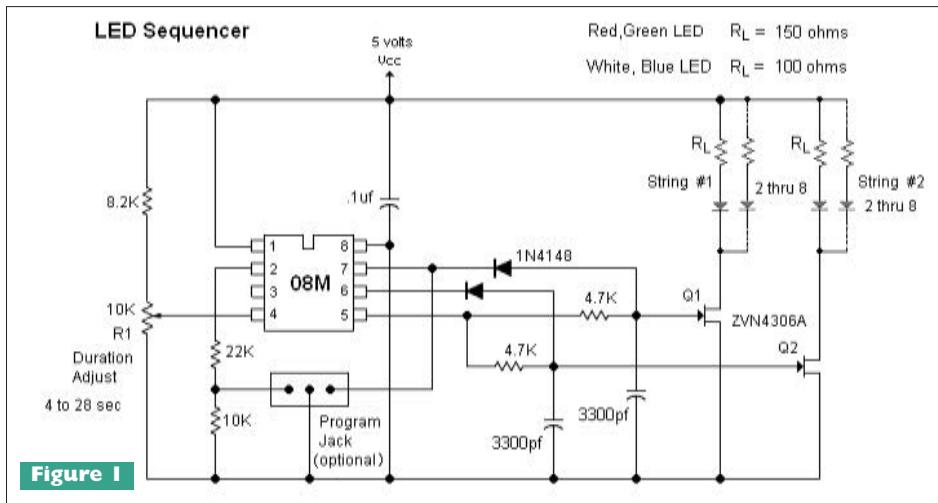
Jim Hicks DVM
Fernandina, FL

>>> ANSWERS

[#12084 - December 2008]

Variable Brightness of LEDs

I have two sets of eight LEDs. The sets need to turn on alternately, with the brightness turning on gradually, then fading out.



As far as controlling the LED brightness, here are two possible solutions: one using PWM (pulse width modulation) and the other a variable DC power source. First, I'll describe the PWM circuit in **Figure 1** which is controlled by a PICAXE 08M microprocessor. The output from a PWM generator is programmed to run continuously. The timing duration is controlled by the ADC reading on potentiometer R1. The LEDs are controlled by FETs Q1 and Q2. All parameters are set by the programming code. **Figure 2** uses a combination triangle-square wave generator (U1) to control the variable DC voltage from Q3. R2 controls the duty cycle and R1 controls the minimum DC output from Q3. The setting of R1 will depend on the color and/or type of LEDs used. Basically, R1 is adjusted so the LEDs just shut off before the counter advances. The square wave output (pin 7 of U1) is

used to advance the 4017 (U2) which is configured as a count to two and recycle counter. The square wave output switches low at each minimum crossing of the triangle generator. This is used to control the "clock enable" (pin 13) on U2. The clock input is connected to Vcc so the counter will advance each time pin 13 goes low. One nice feature about this circuit is the 4017 allows for easy expansion (up to 10) if more LED strings are needed.

There were no details mentioned about the LED strings regarding how they are wired, the color, or voltage needed. In this case, I decided to show both circuits operated with the LEDs in parallel with individual current limiting resistors. The RL values shown are only guidelines as the specs on the LEDs and the brightness required by the user will vary. Both circuits require a regulated 5 VDC power source.

Steve Ghio
Jacksonville, FL

[#12082 - December 2008]**PV vs. EMR**

Since solar panels are inherently a diode, would they survive the electromagnetic burst of an EMR weapon?

Semiconductor survivability under EMP (electro-magnetic pulse) depends on the design which must somehow limit the current when all junctions are conducting. In the case of solar panels, the cells will be destroyed by the reverse current from the charged battery unless there is a series resistor or thermal breaker. The diode that protects against reverse current will be turned on also, so that is no help. A shielded reverse current relay might work but I would rather rely on the thermal breaker.

**Russ Kincaid
Milford, NH**

[#12088 - December 2008]**Testing Components**

How can you differentiate a bad transistor from a good one?

The circuit in **Figure 3** will allow you to test if a transistor is good and what type it is, NPN or PNP.

When you test a transistor, LED 1 or LED 2 will light showing the type of transistor it is. If you press S2 and neither LED lights, switch to S1 and try again. You should get one of the LEDs to light. If not, the transistor is bad.

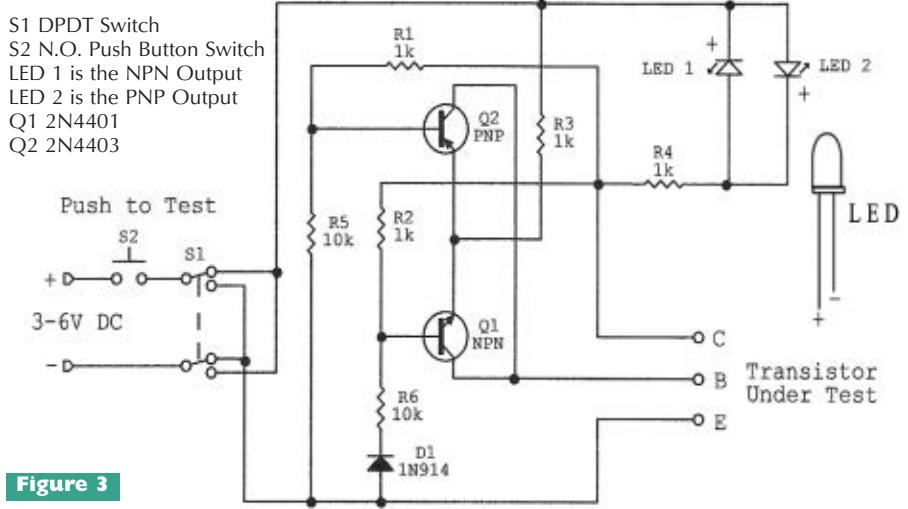
**Allen Resignal
Pittsburgh, PA**

[#1092 - January 2009]**Three-Phase Power**

Does anyone know of a simple, inexpensive, but very accurate way to monitor three-phase current in brushless motor circuits? The method should require, at most, one channel of ADC.

#1 The simplest way to determine the total current consumed by the brushless motor is to measure the DC input to the motor controller, rather than measure and accumulate the current on its three distinct outputs.

Although a traditional current shunt resistor method can be used with your microcontroller's ADC, I would recommend the Allegro



ACS755 current sensor. These are available up to 200 amps and provide full isolation from the measured current because they are Hall-effect devices. Lower current applications can use the ACS715. A single ADC input on your microcontroller is all that is needed to measure the current sensed by the Allegro device.

**T. Black
Folsom, CA**

#2 You can always monitor the current in the DC-Intermediate Loop. A modern set-up has the following topology: a rectifier (synchronous or conventional), power factor correction switcher, DC intermediate loop (may need braking resistors to avoid high voltages), and an H-bridge, motor. The rectifier is not necessary if the supply is DC. Monitoring the current in the DC-Loop will give you a good indication of the overall motor current, especially after the filter caps. However, there are some downsides, especially if the drive is regenerative and can feed back into the power grid. This is a necessity for drives which have a significant amount of braking to do. Consider start/stop cycles, and some drives run almost entirely as brakes.

**Walter Heissenberger
Hancock, NH**

[#1094 - January 2009]**Svideo Luminance**

I have a DVD player with Svideo out; I need to build a simple circuit to use the luminance pins to trigger a

relay as soon as luminance is black.

The solution to this problem breaks down to these basic functions: In **Figure 4**, Q3 and Q4 first buffer and amplify the input signal to two volts peak-to-peak. Secondly, Q1, Q2, C2, and R13 clamp the negative-going sync tips to 1.29 VDC (determined by R2 and R8). This is called "DC-restoration." Thirdly, U1 performs a voltage comparison against a video black reference input on pin 2. U1 pin 7 goes high as video falls to black, cutting relay coil current.

LM311 comparators are capable of driving sensitive relays directly. You must use a relay with at least 100 ohms of coil resistance. D1 protects U1 from inductive kickback. R11 and C3 filter out sync and average DC-restored video into a slowly moving DC voltage, but also cause up to 300 mS of delay in recognizing the black level. R6 provides a little hysteresis to prevent relay chatter near the detection threshold. Adjust R6 if necessary. Only a few millivolts of hysteresis should be sufficient. Tentative values for R4 and R14 are given because you will need to experiment with the black level reference. You should aim for about 1.9 VDC at the junction, but it's likely that you will need to optimize this voltage for the best detection accuracy. Use a pot if desired. Remove R6 temporarily if it interferes with this adjustment. The specified 1% tolerance resistors aren't mandatory

unless you need repeatability for manufacturing purposes. This circuit is based on proven designs, but has not been tested as drawn. Add power supply bypass caps, and read the LM111 datasheet if things don't go well in the lab.

Mike Hardwick
Decade Engineering

[#1095 - January 2009]

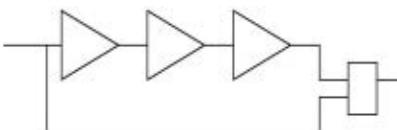
One Minute (or More) Timer

I need a way to reliably trigger a 555 from a loss of input signal. I've tried several schemes involving capacitor discharge when the input disappears but they have not proven to be reliable. Keeping the input high apparently doesn't let the device time out, so it needs to be a positive-going pulse.

#1 Well, my first thought was to hark back to an article here in N&V a while back where it was noted that a certain PIC was cheaper than a 555 timer chip(!), and thinking "Well, shucks, get a cheap PIC and program it up to do what you want."

If that's too intense or you want a purely non-computer solution, then you need a 'signal conditioning circuit' prior to your 555. In this case, this may be as simple as a capacitively-coupled input circuit (a simple RC circuit that I don't think I'd better try to draw with ASCII graphics). You indicate that you've had some trouble with reliability with capacitor discharge circuits — what you want is capacitor INPUT, not discharge.

However, it may be easier to rig up some sort of one-shot circuit, using either a 'one-shot' IC, or use an inverter chip (usually with six or eight inverters), using some of the inverters as delay elements. So, you would wire three, four, or more inverters



(or buffers) as sort of a delay line (above) to feed a delayed signal to the last gate, which is drawn in my figure as a box, but which should be either an xor or perhaps a nand. The idea here is that there is a short time (gate delays) where the inputs will be different. Depending upon whether you need a positive or a negative pulse upon trigger (and the polarity of your trigger, AND whether you use buffers — as I drew — or inverters), you may need a NAND, an XOR, an XNR, or an AND gate (Note: an AND gate is just a NAND with an inverter following, if you don't happen to have an AND handy). Finally, if the pulse isn't long enough after using all the gates, you can insert some more delay by using capacitors and resistors to slow down the rise (or fall) times of the signals passing through your delay line.

Rusty Carruth

#2 Since your design is only working to a certain degree, there are probably some issues with the design itself (an LM555 was assumed).

I. Inadequate power supply

bypassing is highly likely; 1 μ F electrolytic parallel with 0.1 μ F ceramic is recommended and required since the totem pole output has serious current spikes. Keep in mind that the output can source and sink a very high 200 mA. Use high quality components designed for this application.

2. Unused inputs need to be tied to a defined state. The reset input must be tied to Vcc if not used to avoid false triggering.

3. The switch point for the trigger input is 1/3 Vcc. This usually requires a stabilized supply voltage. Use a three-legged regulator.

4. Keep in mind that all capacitors suffer from dielectric absorption (also called dielectric soakage or dielectric memory), an effect which manifests itself when a recently charged and then discharged capacitor bounces back as observed on a high input resistance meter. Teflon, polystyrene, polypropylene are reasonably good, but aluminum and tantalum are really bad choices as dielectric.

5. Prevent feedback from input to output.

6. Most inputs deliver small, varying amounts of current, usually quite temperature dependent.

7. Use a low resistance design on the input circuit to satisfy points three, four, five, and six.

8. A Schmitt-Trigger with high hysteresis on the trigger input may be required for some really difficult applications.

Walter Heissenberger
Hancock, NH

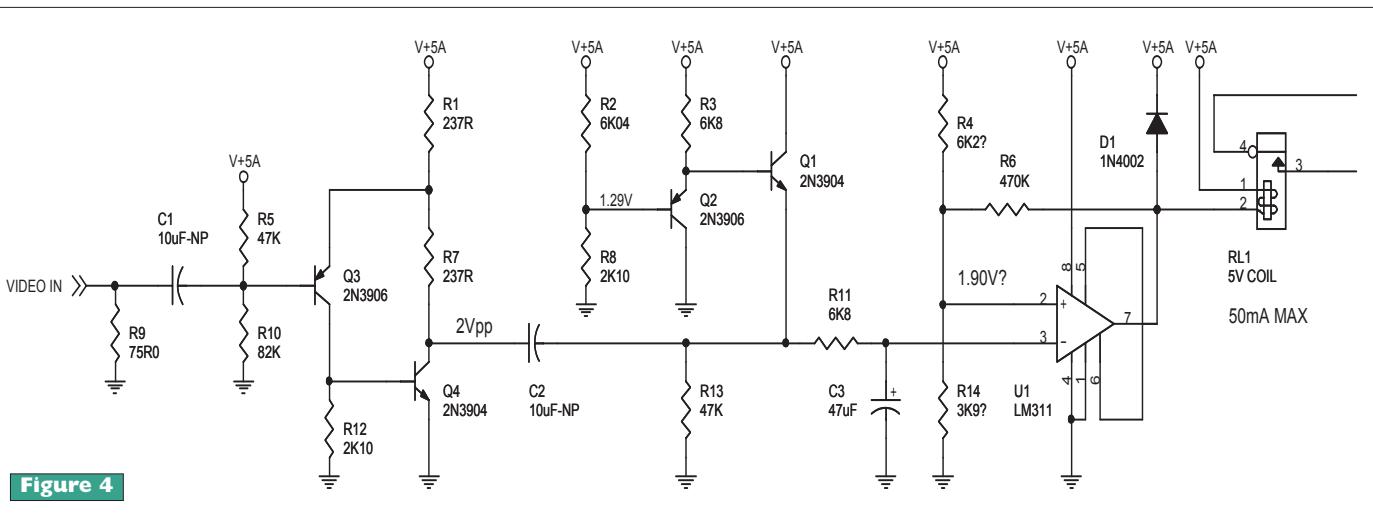


Figure 4

ActiveWire, Inc.	35
All Electronics Corp.	21
AP Circuits	31
Cam Expert, LLC	35
Circuit Specialists, Inc.	99
Comfile Technology	15
Command Productions	9
Cunard Associates	35
Demand Peripherals	35
DesignNotes.com, Inc.	35
Dimension Engineering	8
DLP Design	97
Dynamic Design Mexico	34
Earth Computer Technologies	35
Electronic Design Specialists	73
Electronics 123	35
ExpressPCB	72
Front Panel Express LLC	40
Fun Gizmos	35
HobbyLab	35
Integrated Ideas & Tech.	59
Jameco	4
Jaycar Electronics	11
LeCroy	5
Lemos International Co., Inc.	9
Linx Technologies	33
LITEXPO	35
Lynxmotion, Inc.	32
microEngineering Labs	14
Mouser Electronics	19
NetBurner	7
Net Media	2
PAiA	33
Parallax, Inc.	Back Cover
PCB Pool	43
Pololu Robotics & Electronics	43
QKITS	34
Rabbit, A Digi International Brand	3
Ramsey Electronics, Inc.	22-23
RoboteQ	35
Robot Power	77
Saleae LLC	98
Solarbotics/HVW	10
superbrightleds.com	73
Surplus Gizmos	48
Trace Systems, Inc.	8
XGameStation	35

**AMATEUR
RADIO AND TV**

Ramsey Electronics, Inc.22-23

**BATTERIES/
CHARGERS**

Cunard Associates35

**BUYING ELECTRONIC
SURPLUS**

Earth Computer Technologies35

Jaycar Electronics.....11

**CCD CAMERAS/
VIDEO**

Circuit Specialists, Inc.99

LITEXPO35

Ramsey Electronics, Inc.22-23

CIRCUIT BOARDS

AP Circuits31

Comfile Technology15

Cunard Associates35

Dimension Engineering.....8

ExpressPCB72

PCB Pool43

COMPONENTS

Cam Expert, LLC35

Front Panel Express LLC.....40

Fun Gizmos35

Jameco4

Lemos International Co., Inc.9

Linx Technologies33

NetBurner7

Net Media2

PAiA33

Parallax, Inc.Back Cover

PCB Pool43

Pololu Robotics & Electronics ...43

QKITS34

Rabbit, A Digi International Brand..3

Ramsey Electronics, Inc.22-23

RoboteQ35

Robot Power77

Saleae LLC98

Solarbotics/HVW10

superbrightleds.com73

Surplus Gizmos48

Trace Systems, Inc.8

XGameStation35

Microcontrollers / I/O Boards

Comfile Technology15

Demand Peripherals35

Fun Gizmos35

HobbyLab35

microEngineering Labs14

Mouser Electronics19

Net Media2

Parallax, Inc.Back Cover

Pololu Robotics & Electronics43

Solarbotics/HVW10

Trace Systems, Inc.8

XGameStation35

**DESIGN/
ENGINEERING/
REPAIR SERVICES**

Cam Expert, LLC35

Dynamic Design Mexico34

ExpressPCB72

Front Panel Express LLC.....40

PCB Pool43

Trace Systems, Inc.8

DISPLAY

Comfile Technology15

EDUCATION

Command Productions9

Demand Peripherals35

PAiA33

XGameStation35

EMBEDDED TOOLS

Mouser Electronics19

NetBurner7

ENCLOSURES

Integrated Ideas & Tech.59

KITS & PLANS

DesignNotes.com, Inc.35

Earth Computer Technologies35

Electronics 12335

Jaycar Electronics.....11

NetBurner7

PAiA33

QKITS34

Rabbit, A Digi International Brand....3

Ramsey Electronics, Inc.22-23

Solarbotics/HVW10

XGameStation35

MISC./SURPLUS

All Electronics Corp.21

Front Panel Express LLC.....40

Surplus Gizmos48

MOTORS

Jameco4

PLASTIC PARTS

Dynamic Design Mexico34

PROGRAMMERS

Dynamic Design Mexico34

Electronics 12335

microEngineering Labs14

**RF TRANSMITTERS/
RECEIVERS**

Linx Technologies33

LITEXPO35

ROBOTICS

Demand Peripherals35

Fun Gizmos35

HobbyLab35

Jameco4

Lemos International Co., Inc.9

Lynxmotion, Inc.32

Net Media2

Pololu Robotics & Electronics43

RoboteQ35

Robot Power77

Solarbotics/HVW10

SATELLITE

Lemos International Co., Inc.9

SECURITY

Linx Technologies33

LITEXPO35

TEST EQUIPMENT

Circuit Specialists, Inc.99

DesignNotes.com, Inc.35

Dimension Engineering.....8

Electronic Design Specialists73

HobbyLab35

Jaycar Electronics.....11

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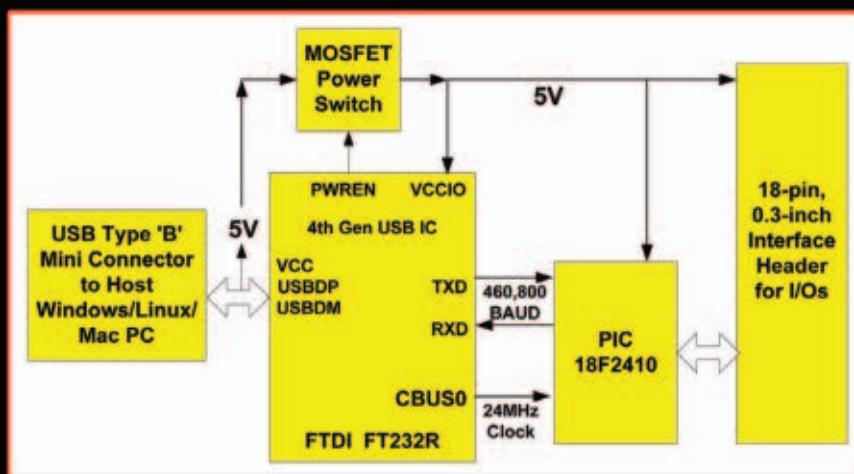
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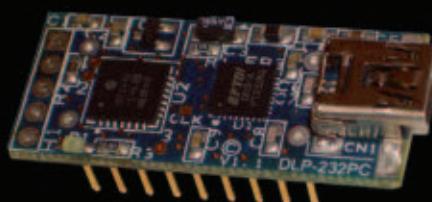
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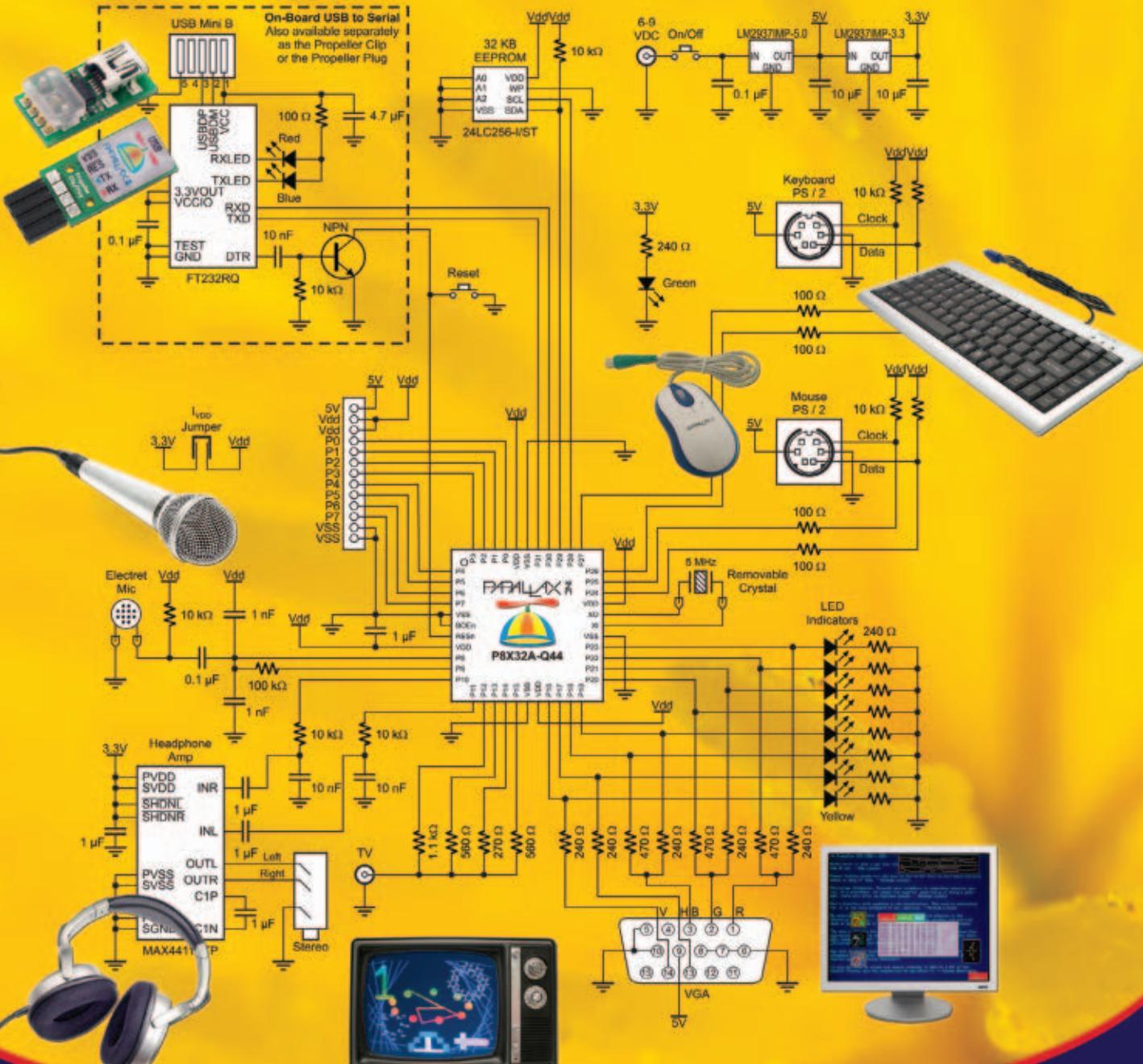


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